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14. ABSTRACT

The overall purpose of this multi-phase research initiative is to create a systematic, data driven, and sustained injury prevention and performance optimization training program to reduce the risk of unintentional, musculoskeletal injuries and enhance military readiness in 101st Airborne/Air Assault soldiers. Improvements in the biomechanical, musculoskeletal, physiological, and nutritional characteristics of soldiers of the Army 101st Airborne/Air Assault will result in improved safety and performance of the individual soldier as potentially injurious tasks are able to be performed more efficiently while prolonging the deleterious influence of fatigue. Also, soldiers will be able to achieve military body weight and fat standards, lower long-term chronic disease risk, promote active duty longevity, and enhance the quality of life after the military. Optimal physical and physiological characteristics will ultimately decrease the time lost due to disability, improve losses due to personnel attrition, and reduce the financial burden associated with medical expenses and disability payments, while promoting military readiness of the tactical athlete.

15. SUBJECT TERMS
Injury prevention, performance decrement, biomechanics, musculoskeletal, physiological, nutritional

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INTRODUCTION
In 2003, the Department of Defense and the Armed Forces Epidemiological Board identified musculoskeletal injury prevention research as a necessary focus. Unintentional musculoskeletal and overuse injuries during tactical operations training, combat, and physical training are a principal health concern in the military given the considerable investment per Soldier. Soldiers of the 101st Airborne (Air Assault) have been described as tactical athletes given the functional demands of operational training and combat. Considering the vigorous demands of tactical operations training, combat, and physical training, implementation of a 101st Soldier-specific injury prevention and performance optimization training research initiative is warranted. The purpose of this multi-aim research initiative is to systematically and scientifically address the current injury prevalence to 101st Airborne Division (Air Assault) Soldiers, identify modifiable injury risk factors, and optimize physical readiness.

The 101st Airborne (Air Assault) Injury Prevention and Performance Optimization Program is a joint research project between the University of Pittsburgh, Department of Sports Medicine and Nutrition, and the Division Command, Division Surgeon, and Blanchfield Army Community Hospital of the US Army 101st Airborne Division (Air Assault) at Fort Campbell. This project is funded by the United States Department of Defense and is under the auspices of US Army Medical Research and Materiel Command/Telemedicine and Advanced Technology Research Center (*Injury Prevention and Performance Optimization in 101st Airborne Soldiers*, W81XWH-06-2-0070 and W81XWH-09-2-0095).

Research activities included performing 101st Airborne (Air Assault) Soldier-specific task and demand analyses for the purposes of identifying the operational and training-related tasks during which musculoskeletal injuries occur. These data were used to create laboratory models to identify suboptimal biomechanical, musculoskeletal, physiological, and nutritional characteristics that increase the risk of training and tactical injuries while reducing the capacity for peak operating readiness. Based on the laboratory results from over two years of testing, the Eagle Tactical Athlete Program (ETAP) was developed and validated for implementation into Division PT. The Instructor Certification Course (ICS) was developed to educate NCOs on the theory, performance, and implementation of ETAP. Upon completion of ICS, ETAP was fully instructed to the individual Soldier units.

This project has provided immediate and tangible deliverables that will continue to enhance the Soldiers' war time deployment preparation. Long term solutions for optimizing the training needs of the Soldier will be established by providing a sustained human performance optimization approach that meets the unique demands of the tactical athlete. Improvements in the biomechanical, musculoskeletal, and physiological risk factors that are known to contribute to injury will result in a reduction of unintentional, musculoskeletal and overuse injuries and optimal physical readiness of 101st Airborne (Air Assault) Soldiers. Ultimately, Soldiers in the 101st Airborne Division (Air Assault) will demonstrate improved safety and enhanced tactical readiness which will result in decreased time lost due to disability, personnel attrition, and the financial burden associated with medical expenses and disability compensation.

BODY

Project Overview

To evaluate the efficacy of ETAP to modify biomechanical, musculoskeletal, and physiological characteristics
A randomized controlled trial was used to validate the Eagle Tactical Athlete Program (ETAP) to modify suboptimal biomechanical, musculoskeletal, and physiological characteristics previously identified by the research team in W81XWH-06-2-0070. A sample of 57 male and female Soldiers from the 101st Airborne Division (Air Assault) participated. Subjects assigned to the experimental group performed an 8-week trial of ETAP, while subjects in the control group performed standard PT according to the current requirements of FM 21.20. ETAP consisted of five main workout sessions per week, each focused on a different fitness component. Each workout session began with a dynamic warm-up and finished with a cool-down and static stretching. Each session was dedicated to one of the following training objectives: Day 1) speed, agility, and balance; Day 2) muscular strength; Day 3) interval training; Day 4) power

development; and Day 5) endurance training. The eight week validation trial was comprised of 35 training sessions and accounted for five days of no scheduled activities. The average attendance was 89% (31 sessions) with a range of 54-100%. Eighty percent of the subjects attended a minimum of 80% of the training sessions. Soldiers performing ETAP demonstrated improvements of 7-28% in variables that are vital to physical readiness, improving the athleticism of the Soldier, and reducing the likelihood of musculoskeletal injury. The observed training adaptations will have long-term implications to improve physical readiness of the Soldier when ETAP is periodized across a 10-12 month pre-deployment cycle.

To pilot the implementation of ETAP into PT
The objective of this aim was to pilot the implementation process of the newly validated ETAP into unit level PT. This aim identified any potential logistical concerns which may have needed modification to ensure successful implementation to the Division. Classes consisted of NCOs who are responsible for administering unit level PT. The NCOs learned the theory and implementation of ETATP and at the completion of the course be certified as Eagle Tactical Athlete Training Leaders. The ICS curriculum covered training program design and implementation, exercise techniques and selection, basic exercise physiology, and nutrition. Each ICS class was scheduled for four days, with a maximum enrollment 30 NCOs per class. Separate classes were scheduled for five weeks, totaling approximately 150 NCOs. It was recommend that each platoon send 2-3 NCOs to the school together to better implement the program in their unit. Classes were held at the Research Center for Injury Prevention and Human Performance from 0930 – 1500 each day. The NCOs participated in the ETAP each morning and received both lecture and practical education. The certified NCOs received planning materials and exercise descriptions to assist in the delivery of the program. Quality control audits were conducted by the University of Pittsburgh personnel to ensure proper delivery of this training program by the NCOs to their units, answer questions related to the implementation, and assess correct performance of the exercises by the Soldiers at the unit level.

To formally implement the validated ETAP into daily PT and monitor effectiveness to reduce injuries and optimize performance
ETAP was formally phase implemented into Division physical training. Following the format of the ICS pilot, Division implementation of ETAP involved a two-step process including, Instructor Certification School (ICS) and unit exposure. To date, 1009 Soldiers have been enrolled in ICS. ETAP was extended from the validated eight week format to a monthly periodized program to be performed during predeployment training. The monthly program contained the same principles by which the eight week model was developed, but modified the progression of each training modality to account for the longer duration (deployment schedule-dependent). The weekly training format was the same with individual days dedicated to a single training principle with allowances built into the program to account for combat focus training. An estimated 20,180 Soldiers have been exposed to ETAP as their physical training.

Monitoring of unintentional musculoskeletal injuries occurred during garrison and deployment to test the efficacy of ETAP to mitigate injuries. A clinical trial design was used to compare injury rates between an experimental and control group. Soldiers in 1BCT and 4BCT served as the experimental group, while Soldiers in 3BCT served as the control group. These Brigades were selected because of their commonality in tactical missions (considered like units) and deployment to same theater. Data were extracted from AHLTA by personnel from Blanchfield Army Community Hospital and provided to the research team at a rate of approximately 30 records per month. As part of W81XWH-11-2-0097, unintentional musculoskeletal injuries will continue to be evaluated during garrison and deployment. To date, a total of 2032 Soldiers have been enrolled into the injury surveillance phase with additional enrollment scheduled upon redeployment of 3BCT. Injury data will be collected 12 months pre-ETAP and 24 months post-ETAP.

Soldiers of the 159CAB were enrolled to confirm knowledge transfer and compliance, progression, and establish long term effects of ETAP on performance. Baseline and the first interval test were performed on 51 Soldiers following ICS implementation. The second interval test will be performed through the next deployment/redeployment cycle as part of W81XWH-11-2-0097.

To develop and present a nutritional education seminar series with outreach materials
Data from the 101st Airborne Division (Air Assault) classified 26% of Soldiers above the Army gender and age specific standards for both weight for height and body fat. These Soldiers performed suboptimally on various physiological and musculoskeletal tests. Nutrition education materials were developed for inclusion in ICS.

To develop a military performance and epidemiology database from which specific injury and performance related queries may be processed
A military performance and epidemiology database was developed and rearchitected to facilitate an analysis of the factors associated with performance and injuries and help to determine training or injury recovery progression. Data entry requires approximately one hour for each subject. Soldier records for 1153 subjects were entered into the system for analysis.

To process and interpret all research data collected at the 101st Airborne Division (Air Assault) Human Performance Research Laboratory
All research data collected at the Research Center for Injury Prevention and Human Performance were processed at the Neuromuscular Research Laboratory. For every one hour of laboratory testing at Fort Campbell, approximately four hours of data processing were necessary to complete the identified tasks (independent of injury data entry). Weekly/monthly meetings were held with the University of Pittsburgh faculty and 101st Airborne Division (Air Assault) investigators to discuss and interpret the results. The investigators will continue to process all data gathered as part of W81XWH-11-2-0097.

To develop new methodologies to identify risk factors for unintentional musculoskeletal injury
New research procedures and training were developed for implementation of research aims as part of W81XWH-11-2-0097. In consultation with USAMRMC/TATRC the research aims for W81XWH-11-2-0097 were revised and the new methodologies were eliminated.

KEY FY 09 RESEARCH ACCOMPLISHMENTS
- Developed and validated ETAP to improve modifiable biomechanical, musculoskeletal, and physiological characteristics
- Developed Instructor Certification School (ICS) as educational tool to implement ETAP
- Enrolled 1,009 Soldiers in ICS and implemented with an estimated exposure rate of 20,180
- Implemented injury surveillance system to establish effects of ETAP
- Identified biomechanical adaptations resulting from load carriage
- Identified decrements in performance variables resulting from excessive body fat above the Department of Defense standards

REPORTABLE OUTCOMES

Abstracts
Fleishman K, Crawford K, Abt J, Sell T, Lovalekar M, Nagai T, Deluzio J, Rowe R, McGrail M, Lephart S. Optimal Body Composition for Performance of 101st Airborne (Air Assault) Soldiers. Medicine and Science in Sports and Exercise. 42 (5) Suppl 1: 622, 2010.

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Manuscripts
Crawford K, Fleishman K, Abt JP, Sell TC, Nagai T, Deluzio J, Rowe R, McGrail M, Lephart SM. Less Body Fat Improves Physical and Physiological Performance in Army Soldiers. Military Medicine. 176(1): 35-43, 2011.

Sell TC, Abt JP, Lovalekar M, Crawford K, Nagai T, Deluzio JB, Smalley BW, McGrail MA, Rowe RS, Lephart SM. Warrior Model for Injury Prevention and Human Performance- Eagle Tactical Athlete Program (ETAP) Part 1. Journal Special Operations Medicine. 10(4): 2-21, 2010.

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Sell TC, Chu Y, Abt JP, Nagai T, Deluzio JB, McGrail M, Rowe R, Lephart SM. Additional Weight of Body Armor Alters Air Assault Soldiers' Landing Biomechanics. Military Medicine. 2010: 175, 41-7.

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Grant Submissions
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CONCLUSIONS

ETAP was developed based on two years of data collection to meet the tactical demands of the 101st Airborne Division (Air Assault) Soldiers. ETAP was validated to induce favorable adaptations in musculoskeletal and physiological characteristics required for physical and tactical training. ETAP will continue to be tested as part of W81XWH-11-2-0097 to validate its effectiveness to mitigate unintentional musculoskeletal injuries and optimize performance.

REFERENCES
Not applicable

APPENDICES

Crawford K, Fleishman K, Abt JP, Sell TC, Nagai T, Deluzio J, Rowe R, McGrail M, Lephart SM. Less Body Fat Improves Physical and Physiological Performance in Army Soldiers. Military Medicine. 176(1): 35-43, 2011.

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SUPPORTING DATA
Not applicable

Less Body Fat Improves Physical and Physiological Performance in Army Soldiers

Kim Crawford, PhD*; Katelyn Fleishman, MS*; John P. Abt, PhD*; Timothy C. Sell, PhD*;
Mita Lovalekar, PhD*; Takashi Nagai, MS†; Jennifer Deluzio, MS†; LTC Russell S. Rowe, MD‡;
LTC Mark A. McGrail, MD§; Scott M. Lephart, PhD*

ABSTRACT The purpose of this study was to compare physical and physiological fitness test performance between Soldiers meeting the Department of Defense (DoD) body fat standard (≤18%) and those exceeding the standard (>18%). Ninety-nine male 101st Airborne (Air Assault) Soldiers were assigned to group 1: ≤18% body fat (BF) or group 2: >18% BF. Groups 1 and 2 had similar amounts of fat-free mass (FFM) (66.8 ± 8.2 vs. 64.6 ± 8.0, $p = 177$). Each subject performed a Wingate cycle protocol to test anaerobic power and capacity, an incremental treadmill maximal oxygen uptake test for aerobic capacity, isokinetic tests for knee flexion/extension and shoulder internal/external rotation strength, and the Army Physical Fitness Test. Results showed group 1: ≤18% BF performed significantly better on 7 of the 10 fitness tests. In Soldiers with similar amounts of FFM, Soldiers with less body fat had improved aerobic and anaerobic capacity and increased muscular strength.

INTRODUCTION

In 1976, the Army Weight Control Program 600-9[1] (AR 600-9) underwent a significant revision, which resulted in combining the U.S. Army Physical Fitness and Weight Control Program regulations in response to concerns that Army personnel were becoming too sedentary, fat, and unable to maintain desired levels of physical fitness.[1] The primary objective of the AR 600-9 is to ensure that all Army personnel are able to meet the physical demands of their duties under combat conditions. It is a mandatory weight control program that uses body weight and percent body fat (% BF) to assist in establishing and maintaining health, optimal physical fitness, and operational readiness.[1]

There is great debate, however, over ideal body composition for military personnel to optimize physical fitness and performance on the battlefield. Identifying "ideal" body composition standards in military personnel is complicated by the diverse, multifaceted requirements of military training and missions. Unlike elite strength/power athletes who benefit from a higher body weight and greater lean body mass and elite endurance athletes who benefit from carrying less body weight and low fat mass, the tactical athlete engages in

military training and missions that require adeptness in both of these fitness areas. Given these requirements, it appears that a large, lean body composition with less body fat would best meet the demands of military performance. The difficulty lies in the fact that the Army is recruiting from an American population that is 68% overweight/obese;[2] of this population, more than 9 million adults aged 17 to 24 are too overweight to join the military.[3] "Today's Soldiers are larger than ever before, a desirable Army trait—"large and in charge"—with appearance of fitness and formidable size."[4]

Scientific evidence, however, is equivocal regarding the impact a larger body size has on physical fitness and military performance in the contemporary Soldier. Research substantiates that excess body weight as fat-free mass (FFM) will improve performance on standardized strength tests, as well as physical tasks involving carrying and lifting.[5,6] If, however, the strength tests require moving body mass through space or if body mass serves as the external load, lean body mass is not associated with increased muscle strength performance.[7] Mattila et al.[8] found that lean body mass was not associated with muscle strength measured by standing long jump, push-ups, sit-ups, pull-ups, and back extension.[8] Additionally, because muscle mass does not proportionately increase with body mass, larger individuals may be at a disadvantage in maneuvering their own bodies.[9]

Excessive total body mass has been associated with impaired aerobic fitness[4] and performance on a variety of military readiness tests.[8,10–12] If excess weight is predominantly fat mass, research is consistent that higher % BF does not optimize fitness or performance.[8,10,11,13] A prospective study of 140 Army recruits showed that a 1% increase in fat shortened the 12-minute running distance by 19.3 meters.[8] Moreover, higher % BF has been shown to negatively affect military performance on tasks that require both strength and aerobic components such as loaded marching.[6,14]

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A report from the Armed Forces Health Surveillance Center revealed a drastic rise from approximately 25,000 to 70,000 active component military service members diagnosed as overweight between 1998 and 2008.[15] Given the ambiguity between "overweight" and "overfat," research is warranted to investigate whether there is an appropriate % BF that would significantly improve strength, aerobic, and anaerobic fitness compared to those with a higher % BF, regardless of total body weight.

The purpose of this study was to compare performance on physical and physiological tests between Soldiers meeting the Department of Defense (DoD) body fat goal (≤18%) and those exceeding the goal (>18%). It was hypothesized that male Soldiers with less % BF (≤18%) would perform better on physical and physiological fitness tests and the Army Physical Fitness Test compared to Soldiers with higher % BF (>18%).

METHODS

Subjects

Ninety-nine male subjects were recruited from the Army 101st Airborne Division (Air Assault) to participate in this study. Approval was obtained from the University of Pittsburgh's Institutional Review Board, Eisenhower Army Medical Center, Clinical Investigation Regulatory Office, and the Human Research Protection Office as part of an ongoing research project focusing on injury prevention and performance optimization in the 101st Airborne Division (Air Assault).

FIGURE 1. Body fat analysis.

Dependent Variables

Body composition, measured as % BF, was used to categorize subjects into groups on the basis of DoD body fat goals:[16] group 1: ≤18% BF and group 2: >18% BF. Physiological variables included anaerobic power (PNAP) and anaerobic capacity (MNAP); maximal oxygen consumption (VO_2max); peak isokinetic knee extension (AKE) and flexion (AKF); peak isokinetic shoulder internal (ASIR) and external rotation (ASER); and the Army Physical Fitness Test (APFT). Laboratory testing was performed in the Research Center for Injury Prevention and Human Performance at Fort Campbell by the same research associates on 2 separate days, with at least 24 hours separating each test day. Body composition, isokinetic strength tests, and anaerobic capacity were tested on day 1 and VO_2max was performed on day 2. The components of the APFT were performed on the same day on a separate occasion in a field setting. Although the primary purpose of the tests was to assess the Soldiers' strength and aerobic and anaerobic fitness, achieving and maintaining a high level of each fitness component is critical for Soldiers' combat survivability and overall operational effectiveness.[17,18]

Body Composition

The Bod Pod Body Composition System (Life Measurement Instruments, Concord, California; see Figure 1) was used to measure body composition. The Bod Pod utilizes air-displacement plethysmography to measure body volume and calculate body density. The Bod Pod is a valid method of body composition measurement in comparison with the gold standard, hydrostatic weighing, in heterogeneous samples, and has been used to assess body composition across a variety of populations.[19-24] Intrasubject reliability within our laboratory has demonstrated reliability and validity (ICC = 0.98, SEM = 0.47% BF). The system underwent a standard calibration utilizing a 50.683 L calibration cylinder and an additional two-point calibration before each test. Subjects wore spandex shorts and swim caps. Body volume was measured until two consistent measurements were achieved. Predicted lung volume and an appropriate densitometry equation were used to calculate % BF.[25] Subjects were assigned to group 1: ≤18% BF or group 2: >18% BF to compare the results on the following physiological fitness tests.

Anaerobic Power

Anaerobic power and capacity were measured using a VeloTron cycling ergometer (RacerMate, Seattle, Washington; see Figure 2) during a Wingate protocol.[26] The Wingate protocol is highly valid and reliable[27] and has been significantly correlated with anaerobic run test performance.[28,29] The ergometer was calibrated by pedaling to a velocity according to factory recommendations. Proper seat and handlebar adjustments
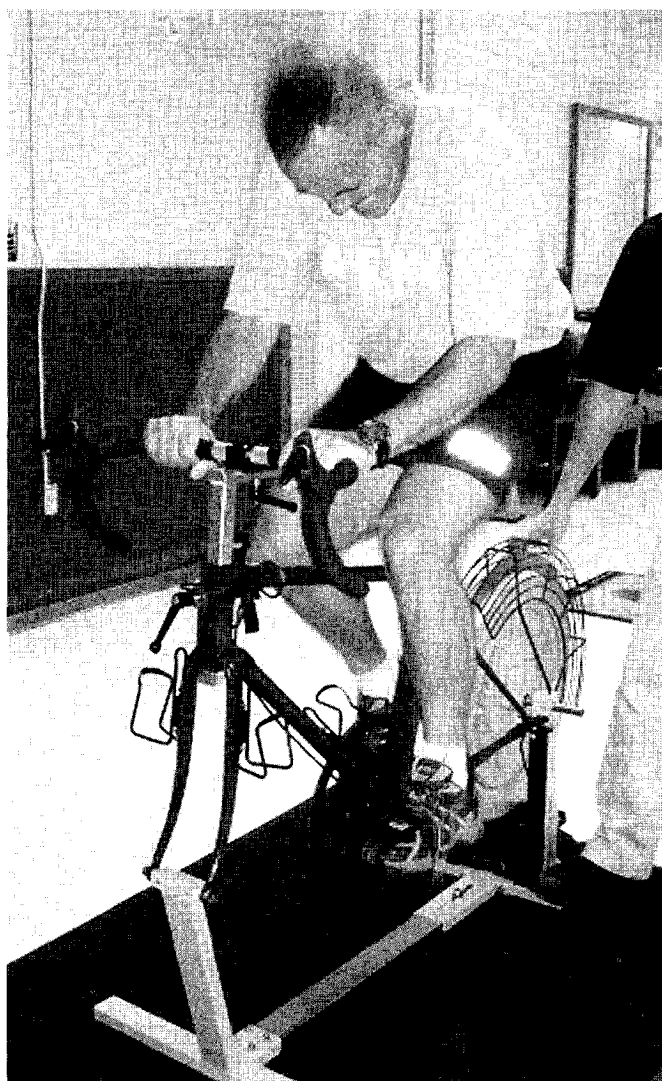
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FIGURE 3. Maximal oxygen uptake test.

FIGURE 2. Wingate test.

were made before the subject's feet were secured to the pedals, and a warm-up cycle at a self-selected cadence was initiated at 125 watts (W). Subjects underwent a 50-second cycling protocol, in which they pedaled at 125 watts for 20 seconds, and then performed a maximal effort sprint for 30 seconds against a braking torque of 9% body weight. Standard verbal instructional cues were provided during the test. Anaerobic power was reported as the peak watts normalized to body weight produced during the first 5 seconds of the test, and anaerobic capacity was reported as the average watts normalized to body weight produced during the entire 30 seconds (W/kg).

Maximal Oxygen Uptake

A portable metabolic system (Oxycon Mobile; Viasys, San Francisco, California; see Figure 3) was used to assess maximal oxygen consumption during an incremental treadmill test. The Oxycon Mobile is a valid metabolic system, showing less than 3% difference compared to simulated VO_2 during

a maximal cardiopulmonary exercise test.[30] The instrument was calibrated with known gas mixtures and measured values corrected to standard temperature, pressure, and density. A heart rate monitor (Polar USA, Lake Success, New York) was worn by the subject around the chest at the level of the zyphoid process. The subject performed a warm-up at a self-selected speed on the treadmill for 5 minutes before testing. A modified incremental protocol[31] was used to reach VO_2max, with subjects running at a constant speed and a 2.5% increase in grade at the end of each 3-minute stage. The subjects' speed was determined as 70% of the mile pace from their 2-mile run time during the APFT. Subject termination was determined by volitional fatigue. Maximal VO_2 is reliable and highly predictive for evaluating differences in aerobic fitness across populations[6] and was reported normalized to body weight (mL/kg/min).

Army Physical Fitness Testing

The APFT was conducted by the individual military units on a separate occasion. Push-up and sit-up tests were performed according to the Army standard protocol,[32] which records the

maximal number of repetitions completed in each 2-minute timed period. Push-ups and sit-ups are widely accepted as valid indicators of muscle strength and endurance.[7]

A 2-mile run timed test was conducted and the amount of time needed to run the distance of 2 miles was recorded.[32] Distance runs are highly correlated with aerobic capacity.[6,7,33]

Musculoskeletal Assessment

Bilateral isokinetic strength of the knee (flexion/extension) and shoulder (internal/external rotation) was assessed using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Shirley, New York; see Figure 4). The reliability of isokinetic strength testing had been established in our laboratory (ICC = 0.73–0.97) for peak torque/body weight.

Isokinetic knee extension and flexion dynamometry are highly reliable (ICC = 0.96–0.97 and ICC = 0.93–0.98, respectively)[34–37] and valid[36,38,39] measures of quadriceps and hamstring muscle performance that identify military personnel at risk for overuse knee joint injury,[40–44] and significantly predict hopping, leaping, and jumping ability (r = 0.62–0.92, p < 0.05 for extension and r = 0.65–0.69, p < 0.05 for flexion)[45–47] as well as straight-line and agility sprint performance (r = −0.42 to −0.51, p < 0.05 for extension and R > 0.55, p < 0.05 for flexion).[45,48–50]

Isokinetic shoulder internal rotation and external rotation dynamometry is a highly reliable (ICC = 0.78–0.92)[51–53] and valid[36,38,39] measure of rotator cuff muscle performance, of which optimal function is considered critical in shoulder injury prevention programs.[54,55]

FIGURE 4. Isokinetic shoulder strength test.

To test isokinetic knee and shoulder strength, the subjects were properly fitted to the chair of the device by aligning the axis of joint rotation to the dynamometer axis. For knee strength, the subject was seated with the hip at 90°, and for shoulder strength, the subject was seated with their arm securely fitted to the dynamometer's arm at 30° of shoulder abduction. Padded straps were used to prevent extraneous movements during the test. Dynamometer range of motion stops and limb weight/gravity correction were set. The subject performed three practice trials at 50% maximal effort and three practice trials at maximal effort followed by a 60-second rest period. Peak isokinetic torque for AKE, AKR, ASIR, and ASER was measured across five, maximal effort repetitions (concentric/concentric at 60°/second) and reported normalized to percent body weight.

Statistical Analysis

Data were examined to evaluate the assumptions of normality and homogeneity of variance. Descriptive statistics (measures of central tendency and measures of dispersion) were calculated for all variables. Because the assumption of normality was met for most, but not all of the variables, Mann-Whitney U tests and calculation of the Spearman correlation coefficient were performed. The results of the nonparametric test agreed with the results of the corresponding parametric test (independent samples t-test and Pearson correlation coefficient) with respect to significance of the results (Table II). Though both parametric statistics for normally distributed data and nonparametric statistics are presented in Tables I and II, parametric statistics are reported in the text for all variables (mean ± SD). In post hoc analysis, there was one case (ASIR relative to FFM between groups) when the nonparametric and parametric tests disagreed; in this case, both statistics are presented as this also was a variable that did not meet the assumptions of normality.

For variables where the assumption of homogeneity of variance for the two-sample t-test for independent samples was not met, the t-test for unequal variances (Satterthwaite approximation) was used. Statistical significance was set at 0.05 (two-sided) a priori.

The performance variables included three distinct families—aerobic/anaerobic capacity (PNAP, MNAP, and VO_2max), APFT (push-ups, sit-ups, and run), and muscular strength variables (ASIR, ASER, AKF, and AKE). The Bonferroni procedure was applied within each family of performance variables to correct for the multiple comparisons.

Effect size for the performance variables was calculated using the absolute difference between means and the pooled SD. Statistical analysis was done using SPSS 17.0 (SPSS, Chicago, Illinois.).

RESULTS

Table I lists the demographic and anthropometric data for all subjects. Significant differences were found between group 1: ≤18%

TABLE I. Demographic and Anthropometric Data of Group 1: ≤18% BF and Group 2: >18% BF

		Group 1 (≤18% BF)						Group 2 (>18% BF)						
	n	Median	1st Q	3rd Q	Mean	SD	n	Median	1st Q	3rd Q	Mean	SD	Mann Whitney U	T-test
Age (Y)	44	25.5	22.0	29.0	26.6	6.1	55	30.0	24.0	38.0	30.6	7.2	0.005*	0.004*
Height (in)	44	69.5	68.0	72.0	69.6	3.4	55	70.0	68.0	71.5	69.8	2.5	0.817	0.703
Weight (lbs)	44	170.0	152.5	185.0	169.8	21.2	55	187.9	172.0	215.0	192.5	27.7	0.000*	0.000*
BMI (kg/m²)	44	24.9	23.0	25.9	24.7	2.6	55	26.8	25.4	29.9	27.7	3.1	0.000*	0.000*
BF (%)	44	14.0	11.0	16.0	13.3	3.7	54	25.2	21.1	29.8	26.0	5.4	0.000*	0.000*
Service (Y)	42	4.5	2.8	7.6	6.0	5.2	53	8.0	3.8	14.5	9.0	6.1	0.009*	0.011*
FFM (kg)	44	66.2	60.6	72.8	66.8	8.2	54	63.3	58.4	69.6	64.6	8.0	0.186	0.177
FM (kg)	44	10.7	7.9	13.1	10.3	3.4	54	21.2	16.8	29.0	23.1	7.1	0.000*	0.000*

*Variable showed significant differences in medians and means between groups utilizing Mann Whitney U and T-test with α set a priori at $p = 0.05$.

TABLE II. Comparison of Performance Variables between Group 1: ≤18% BF and Group 2: >18% BF

		Group 1						Group 2							
	n	Median	1st Q	3rd Q	Mean	SD	n	Median	1st Q	3rd Q	Mean	SD	Mann Whitney U	T-test	Effect Size
PNAP (W/kg)	37	12.9	11.8	14.2	13.1	1.8	49	12.1	10.7	13.9	12.4	2.1	0.143	0.117	0.35
MNAP (W/kg)	37	8.3	7.8	8.7	8.3	0.6	49	7.3	6.7	8.0	7.2	1.0	0.000**	0.000**	1.23
VO₂max (ml/kg/min)	44	52.1	48.6	55.6	52.2	5.4	55	44.1	39.4	47.7	44.1	6.8	0.000**	0.000**	1.32
Push-Ups (2 min⁻¹)	36	76.5	64.3	85.8	78.2	18.5	38	68.5	54.0	75.0	65.7	13.9	0.003**	0.002**	0.76
Sit-Ups (2 min⁻¹)	36	74.5	58.0	84.5	73.6	16.2	38	70.5	61.5	82.8	73.1	14.0	0.981	0.892	0.03
Run Time (min)	36	14.8	13.2	16.8	15.2	2.3	38	15.3	13.6	16.2	15.1	2.0	0.955	0.874	0.04
ASIR (% BW)	44	62.4	53.6	75.1	66.1	16.3	54	50.0	37.9	59.3	50.4	14.5	0.000**	0.000**	1.01
ASER (% BW)	44	44.0	40.1	50.5	45.4	7.7	54	36.0	31.0	41.7	36.6	7.4	0.000**	0.000**	1.16
AKF (% BW)	44	125.9	113	146.6	127.9	23.9	54	104.0	85.1	122.6	103.6	26.6	0.000**	0.000**	0.96
AKE (% BW)	44	265.5	229.4	289.5	263.5	49	54	223.0	186.0	251.4	219	41.7	0.000**	0.000**	0.98

*Statistically significant at the 95% confidence level. **Statistically significant after application of the Bonferroni procedure within each family of performance variables. All numbers have been rounded except for p-values.

BF and group 2: >18% BF for body weight, BMI, % BF, age, and years of service. There were no significant differences between groups for height and FFM. Thus, the difference in body weight was due to the difference in the amount of fat mass (FM) and not FFM.

Because the correlations between both age and years of service and the fitness/performance variables were weak (absolute value < 0.3, except for the Pearson correlation coefficient [−0.314] between years of service ASER), no further adjustments were made for age or years of service in studying the association between BF and physical fitness variables.[56,57]

Subjects in group 1: ≤18% BF who met the DoD body fat goal performed significantly better than those in group 2: >18% BF on 7 of the 10 physical and physiological tests performed (Table II). Group 1: ≤18% BF had significantly higher MNAP and VO₂max than group 2: >18% BF ($p ≤ 0.001$). Of the APFT, only push-ups were significantly different between groups, with Soldiers in group 1: ≤18% BF having significantly higher scores than Soldiers in group 2: >18% BF ($p = 0.002$). Group 1: ≤18% BF performed significantly better on all measures of isokinetic strength, including AKE, AKF, ASIR, and ASER ($p < 0.001$).

A post hoc analysis was performed to calculate absolute isokinetic strength and isokinetic strength normalized to FFM.

Absolute strength values were significantly higher in group 1: ≤18% BF than group 2: >18% BF for ASIR ($51.09 ± 14.47$ vs. $43.88 ± 13.67, p = 0.013$) and ASER ($34.96 ± 7.19$ vs. $31.90 ± 7.29$ N*m, $p = 0.040$), and while not statistically significant, group 1: ≤18% BF had higher absolute AKE ($203.52 ± 46.76$ vs. $190.51 ± 41.02$ N*m, $p = 0.146$) and AKF strength ($98.96 ± 23.71$ vs. $89.98 ± 24.23$ N*m, $p = 0.069$). When isokinetic strength was normalized to FFM, there were no significant differences between group 1: ≤18% BF and group 2: >18% BF for ASIR ($52.4 ± 8.6$ vs. $49.4 ± 9.1\%$ FFM, $p = 0.102$), AKE ($304.1 ± 55.5$ vs. $296.0 ± 54.7\%$ FFM, $p = 0.475$), and AKF ($147.6 ± 27.5$ vs. $139.6 ± 33.1\%$ FFM, $p = 0.202$). Isokinetic ASIR relative to FFM was higher in group 1: ≤18% BF ($76.2 ± 18.4$ vs. $67.9 ± 18.1\%$ FFM, t-test $p = 0.026$, Mann-Whitney U $p = 0.054$).

DISCUSSION

In recent years, the Army has been increasingly concerned with the rise in body weight/fat and its effect on physical fitness, battlefield performance, and military appearance. Results from this study suggest that in Soldiers with similar amounts of FFM, those with less body fat and thus weight performed better on tests of anaerobic and aerobic capacity, push-ups, and isokinetic knee and shoulder strength. In general, this

study substantiates, if the excess body weight is from higher body fat mass, overall physical fitness is compromised.

Since excess body fat is noncontractile, does not assist in force generation, increases the force requirements of muscles, weighs the body down during acceleration, and requires more energy to move the heavier mass through space, it is not surprising that it has a negative impact on aerobic performance.[58,59] In this study, group 1: ≤18% BF performed significantly better on the VO_2max test than group 2: >18% BF. In addition, the correlation between % BF and VO_2max was strong ($r = -0.633$, $p < 0.001$), a finding consistent with studies reporting a negative relationship between aerobic capacity and % BF.[4,60] This relationship corresponds to the physiological condition where the capacity for body propulsion is decreased as % BF, or nonenergy-producing tissue, increases.[59] Figure 5 shows that there is some variability in the relationship between % BF and the VO_2max, but in general, aerobic capacity improves with a reduction in % BF.

Sharp et al.[6] reported no significant change in VO_2max in a cohort of Army Soldiers tested at two time periods, 1978 and 1998 (VO_2max 50.7 ± 4.8 and 50.6 ± 6.2, respectively), despite a significant increase in body fat (16.2 ± 5.3% and 18.7 ± 4.8%, $p < 0.05$).[6] The increase in body fat from 16.2% to 18.8%, although statistically significant, is a range of body fat that is below the most stringent maximal allowable body fat level for Army personnel. From our data, as % BF increases above approximately the 15% threshold, there is a more dramatic decrease in aerobic capacity (see Figure 5).

Maximal oxygen uptake and 2-mile run times have been reported to be highly correlated ($r = -0.76$ to -0.91).[5,6,61-63] In the present study, there was a very weak nonsignificant asso-

ciation between 2-mile run time and VO_2max. It is unknown whether subjects performed the APFT at maximal effort during testing or whether they merely performed each task to pass the Army standard requirements. Other researchers have also raised questions regarding the extent to which a Soldier performs maximally vs. achieving the minimal scores needed to pass the AFPT.[6,64] The weak association would substantiate the notion that Soldiers did not perform at maximal effort on the 2-mile run test. This limitation may in part explain why Soldiers in group 1: ≤18% BF did not perform significantly better than Soldiers in group 2: >18% BF on the sit-up and the 2-mile timed run tests.

Limited previous research has evaluated the impact of body composition on anaerobic power and anaerobic capacity. A study examining the relationship between muscle fiber type, body composition, and anaerobic power utilizing a cycle ergometer test found that the morphological variables that had the highest positive correlation to maximal power output were total body mass and fat free mass ($r = 0.54$ and 0.57, respectively).[65] These results may help to explain why there was no significant difference between groups for anaerobic power in our study. Since our results showed that anaerobic capacity was significantly better in group 1: ≤18% BF, this suggests that leaner Soldiers perform better in anaerobic tasks lasting for a longer duration. Figure 6 shows that in general, there is a decrease in anaerobic capacity as % BF increases, with a sharper decline in performance above approximately the 20% body fat level.

Not only is excess body fat negatively associated with aerobic and anaerobic capacity; it has been negatively correlated with measures of strength that use the body as the principal resistance (push-ups, vertical jump) as well as those that do not (isokinetic tests, 1-repetition max).[7,8] Results of the strength testing in this study are in agreement with these findings, in which push-ups and isokinetic AKE, AKF, ASIR, and ASER were significantly, negatively correlated to % BF.
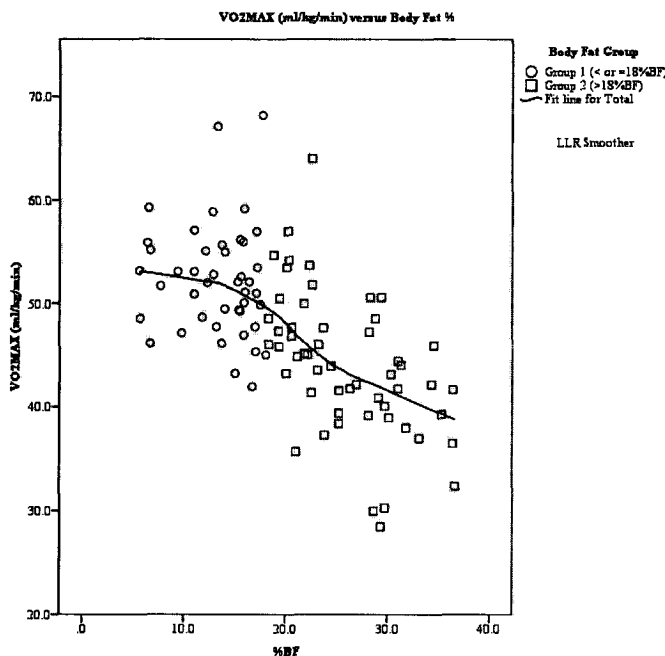

FIGURE 5. Maximal oxygen uptake plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).
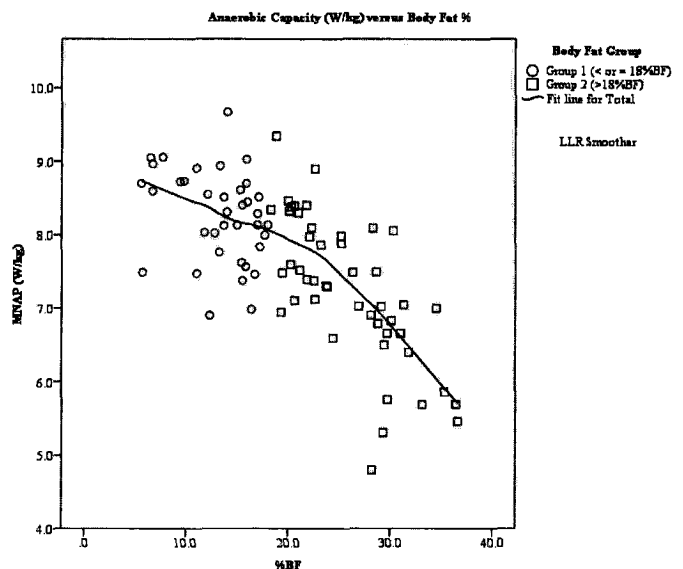

FIGURE 6. Anaerobic capacity plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).
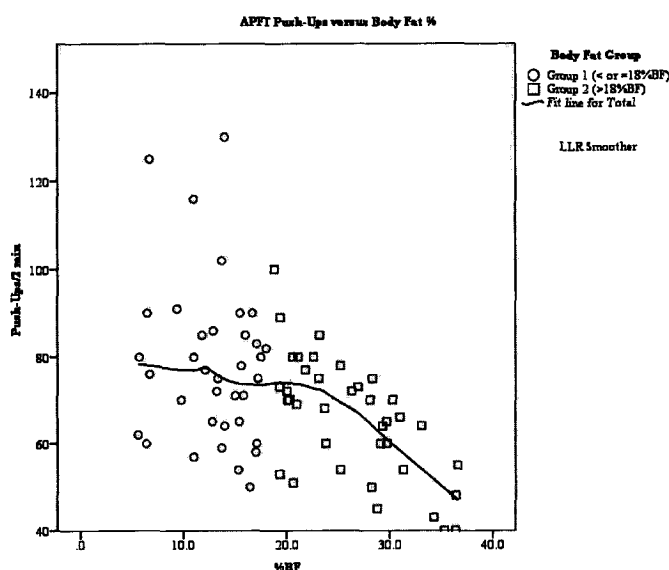
FIGURE 7. APFT push-up score plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).
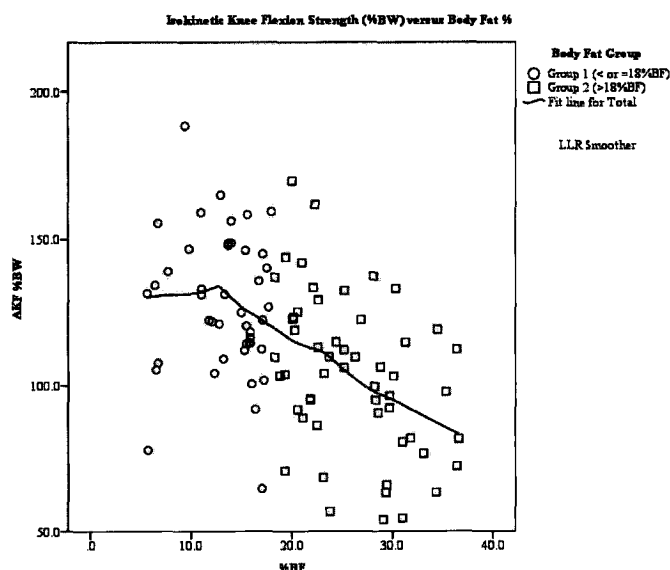
FIGURE 8. Isokinetic knee flexion strength plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

Sit-ups, however, were poorly correlated to % BF. The scatter plot in Figure 7 shows that there is more variability in the relationship between % BF and push-up performance in the lower body fat range; however, above the 20% body fat level, there is a more dramatic decrease in number of push-ups performed.

In a study examining the association between body composition and physical fitness, 140 Army recruits completed strength testing including standing long jump distance; number of sit-ups, push-ups, and pull-ups; back extension; and a 2-mile run.[8] Researchers concluded % BF was the strongest predictor of muscle strength and running performance and that the amount of muscle mass was not related to muscle strength. Although it is generally accepted that as body mass increases, both FFM and strength increase, muscle strength does not proportionately increase with total body mass.[7] There is a point at which the power produced by the higher amount of FFM is not enough to offset the additional body weight and the resistance created increases the energy requirement to perform the work.[9] This may in part explain why Soldiers in our study with less body fat and body weight but similar amounts of FFM (Table II), performed better on the majority of physical fitness tests. Figure 8 depicts the relationship between AKF and % BF, which shows some individual variability, but in general, as % BF increases, knee flexion strength decreases, with a sharper decline at approximately the 15% BF level.

In examining the impact that FFM had on physical performance, Pearson correlation coefficients for FFM and 10 physical fitness tests revealed a very weak, nonsignificant ($r = 0.002$–0.164) relationship. Further, when the isokinetic strength tests were normalized to FFM, there were no significant differences between groups except for ASIR, which trended higher for group 1: ≤18% BF. When normalized to total body mass, each measure of isokinetic strength was significantly higher in group 1: ≤18% BF, suggesting that the

contribution of fat mass to total body mass accounted for the relative decrease in performance. The results of this study reinforce previous research showing that despite possessing similar levels of absolute FFM, individuals with less % BF possess greater levels of aerobic capacity and strength.[8,10,14,66]

The relationship between FFM and muscle strength and endurance is stronger in tests that involve carrying a load and lifting.[9,67] Vogel et al.[59] reported that absolute lifting capacity is directly related to FFM and not related to % BF in men.[59] However, since % BF in contemporary Soldiers is higher, there may be a point in which this higher amount of fat will also negatively impact absolute lifting capacity. Although our strength tests did not directly measure load carriage ability or overhead lifting, the absolute peak isokinetic strength values for ASIR and ASER were significantly greater in group 1: ≤ 18% BF, and while not significant, AKE and AKF showed similar trends. This suggests that in our population, the leaner subjects were able to produce greater absolute strength despite having significantly less total mass. Future studies may benefit from including loaded carry and maximal lifting tests to evaluate whether higher body weight provides a performance benefit or detriment and how that affects the other areas of physical fitness and military performance.

Currently, there is debate over the concept of "large and in charge" body size and how it impacts overall physical fitness and military performance. Critics of the current body weight and fat standards argue that heavier Soldiers perform better on a variety of military tasks such as lifting, pushing, and carrying external loads and that these job tasks are required with greater frequency in specific military occupational specialties (MOS). Although a higher body weight may provide some benefit to certain military tasks, carrying excess weight, as fat, is associated with poor physical fitness. One of the missions of military

training is to improve physical fitness as it is generally accepted that this will increase the likelihood of success in battle.[68,69] Blount et al.[68] reported that a Soldier who is more physically fit can cover a longer distance in a shorter time than someone who is less fit, reducing time in the enemy's line of fire. Excess body fat may have a negative impact on important battlefield requirements including low and high crawl speed and endurance and climbing various terrains for long distances.[68] As the % BF of today's Soldiers continues to rise, research is warranted to determine body fat levels that are optimal for maximizing a wide range of physical fitness parameters and indicators of combat readiness, and further, the impact of losing excess fat on improving military fitness and performance.

The outcomes of this study present practical applications to the military population not only in improving a Soldier's physical fitness and thus military readiness, but helping to reduce a Soldier's risk of injury. Knapik et al.[70] reported that Soldiers with lower aerobic fitness and muscle strength had a higher occurrence of musculoskeletal injuries. Essentially, individuals with excess % BF may possess physiological fitness and musculoskeletal strength deficits, reduced military readiness, and increased risk for unnecessary injury.

CONCLUSIONS

As the body weight/fat of military personnel continues to rise, it is important to identify the impact it has on military training and combat. It is important for the military to employ techniques that provide more direct measures of body fat and FFM to accurately identify Soldiers with excess weight from body fat. This study provides supportive evidence that if the increase in body weight is due to excess body fat, physical fitness is compromised, which ultimately affects military preparedness. Future research is warranted to examine the direct relationship between body composition and physical readiness, which is more specific to a Soldier's MOS, tactical activities, and combat effectiveness.

ACKNOWLEDGMENTS

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Warrior Model for Human Performance and Injury Prevention: Eagle Tactical Athlete Program (ETAP) Part I

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ABSTRACT

Introduction: Physical training for United States military personnel requires a combination of injury prevention and performance optimization to counter unintentional musculoskeletal injuries and maximize warrior capabilities. Determining the most effective activities and tasks to meet these goals requires a systematic, research-based approach that is population specific based on the tasks and demands of the warrior. **Objective**: We have modified the traditional approach to injury prevention to implement a comprehensive injury prevention and performance optimization research program with the 101st Airborne Division (Air Assault) at Ft. Campbell, KY. This is Part I of two papers that presents the research conducted during the first three steps of the program and includes *Injury Surveillance*, *Task and Demand Analysis*, and *Predictors of Injury and Optimal Performance*. **Methods**: Injury surveillance based on a self-report of injuries was collected on all Soldiers participating in the study. Field-based analyses of the tasks and demands of Soldiers performing typical tasks of 101st Soldiers were performed to develop 101st-specific laboratory testing and to assist with the design of the intervention (Eagle Tactical Athlete Program (ETAP)). Laboratory testing of musculoskeletal, biomechanical, physiological, and nutritional characteristics was performed on Soldiers and benchmarked to triathletes to determine predictors of injury and optimal performance and to assist with the design of ETAP. **Results**: Injury surveillance demonstrated that Soldiers of the 101st are at risk for a wide range of preventable unintentional musculoskeletal injuries during physical training, tactical training, and recreational/sports activities. The field-based analyses provided quantitative data and qualitative information essential to guiding 101st specific laboratory testing and intervention design. Overall the laboratory testing revealed that Soldiers of the 101st would benefit from targeted physical training to meet the specific demands of their job and that sub-groups of Soldiers would benefit from targeted injury prevention activities. **Conclusions**: The first three steps of the injury prevention and performance research program revealed that Soldiers of the 101st suffer preventable musculoskeletal injuries, have unique physical demands, and would benefit from targeted training to improve performance and prevent injury.

INTRODUCTION

Unintentional musculoskeletal injury is a persistent and principal health concern for the United States military. Recent epidemiological evidence indicates that 19.5% of troops currently deployed to Iraq and Afghanistan report at least one nonbattle injury with 84.8% of individuals (of the 19.5%) seeking medical attention.[1] Many of these injuries are potentially preventable as 57% involved Sports/Athletics or Heavy Gear/Lifting. Earlier epidemiological studies demonstrate similar findings. In 1992, 31% of all U.S. Army hospitalizations were due to musculoskeletal conditions and injuries.[2] This percentage of musculoskeletal injuries remains high in the current

conflicts.[3] The majority of these injuries were non-combat related[4] musculoskeletal injuries[5-8] and typically occurred during physical training, sports, and recreational activities. The Armed Forces Epidemiological Board has indicated that musculoskeletal injuries have a greater impact on health and readiness than medical complaints during peacetime and combat.[9] Furthermore, musculoskeletal injuries are a leading cause of hospitalization;[2] account for a large number of disability reviews;[7, 10] account for a significant amount of lost duty time;[11, 12] cost nearly one billion dollars yearly in care;[9, 10, 13] result in both short term and long term disability; and place a substantial burden on the

medical system.[14] Although there are a number of identified predictors for unintentional musculoskeletal injuries (age, gender, anatomy, physical activity and fitness, flexibility, smoking, absolute amount of training, type of training, and acceleration of training),[14] they persist as a significant health concern facing servicemen and women and the individuals who care for and command them. Additional research is necessary to identify the modifiable neuromuscular, biomechanical, physiological, and musculoskeletal characteristics that predict injury.

Musculoskeletal injuries are potentially preventable with scientifically driven, culturally-specific, and population-specfic physical training programs. Typically, injury prevention research targets one specific injury, one joint, or one extremity, but injury prevention in the military must be more comprehensive in order to address the most common injuries across multiple joints and all extremities. But, injury prevention alone is only one aspect of a comprehensive physical training program. A successful program will also address physical performance and nutritional needs. Providing nutrients and fluid in the right combination to meet the unique demands of military training and missions will help fuel the muscle demands, allow for optimal adaptation, reduce fatigue and injury, and optimize physical performance. All three components (injury prevention, performance optimization, and nutritional repletion) must be specific to the Soldier based on the specific tasks he has to perform as well as the physical demands placed on him. Addressing specificity is based on

Figure 1: *University of Pittsburgh Injury Prevention and Performance Optimization Model*

a process that we refer to as *Task and Demand Analysis* (Figure 1) and it is part of our approach to injury prevention and performance optimization.

Our approach is based on a conventional public health model of injury prevention and control[15-17] adapted to also include performance and nutrition interventions (Figure 1). Our model incorporates multiple research designs utilizing sound scientific methods to establish the following:

1. Scope and magnitude of musculoskeletal injuries through *Injury Surveillance*
2. Methodological and intervention specificity to meet the demands of distinct groups of service

men who have to perform different tasks that have unique physical and physiological demands with *Task and Demand Analysis*
3. Modifiable neuromuscular, biomechanical, physiological, musculoskeletal, and nutritional characteristics that are *Predictors of Injury and Optimal Performance*
4. Effective training and education programs through the *Design and Validation of Interventions* that modify risk factors for injury and predictors of optimal performance
5. Appropriate procedures for *Program Integration and Implementation*
6. Capabilities of the intervention to reduce the incidence of unintentional musculoskeletal injury and optimize performance as we *Monitor and Determine the Effectiveness of the Program*

Currently, the University of Pittsburgh and the 101st Airborne Division (Air Assault) have established the Human Performance Research Center at Ft. Campbell, KY. The overall purpose of this collaboration is to create a systematic, data driven, and sustained injury prevention and performance optimization program to reduce the risk of unintentional, musculoskeletal injuries and improve physical performance in 101st Airborne/Air Assault Soldiers. Specifically, we are customizing our injury prevention and performance optimization model for application to a specific population of Soldiers.

The first step of the model is *Injury Surveillance*. Data are collected on the target population to understand the magnitude, nature and impact of the injury problem. Data includes the type of injuries (anatomical location, tissues involved, acute, overuse), where injuries occur, activity performed when injury occurred (physical training, tactical operations, for example), and the mechanism of injury. Data are collected utilizing self-report surveys or through queries of existing medical databases.

Task and Demand Analysis is critical component and a hallmark of our model. It provides a means by which the entire injury prevention and performance research model can be implemented within different populations of athletes or Soldiers. Data are collected in the field (physical training and tactical training) an includes both qualitative and quantitative examination of the tasks during which injuries typically occur, examination of the musculoskeletal and biomechanical qualities necessary for efficient and safe functional performance, and the physiological demands of the individual while performing his or her functional tasks. Typically these are single-case descriptive studies. *Task and Demand Analysis* data are incorporated into the identification of predictors of injury and performance as well as the design and validation of intervention programs.

The collection of *Predictors of Injury and Optimal Performance* is the next step and includes collection of subject-specific neuromuscular, biomechanical, physiological, musculoskeletal, and nutritional characteristics. Testing
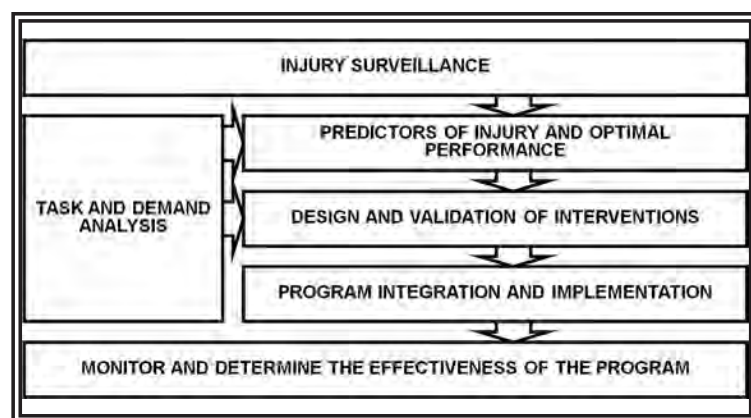
methodology must include task-specific biomechanical analyses as well as musculoskeletal and physiological protocols based on the demands of the target population (see *Task and Demand Analysis* above). The goal is to identify modifiable factors that predict injury and performance that can be targeted with intervention programs. Prospective studies are the most powerful research design to examine these factors. Descriptive and comparative studies can also be utilized to a lesser extent to narrow down and identify potential predictors of injury and performance.

Design and Validation of Interventions are population specific and based on the modifiable injury and performance predictors identified in the previous step. The design of the program must include the specific task and demands (see *Task and Demand Analysis* above) of the target population and can utilize population-specific data (descriptive/comparative studies) and previously identified predictors (existing peer-reviewed literature). Design must consider the environment, venue, and the logistical needs of the population (delivery and integration). The validation of the intervention is focused on the capability of the program to modify the identified predictors of injury and performance and is typically tested through randomized, controlled, clinical trials.

The next step in the model is *Program Integration and Implementation* and requires careful logistical planning and cooperation in order to deliver the intervention to the target population within their environment while accounting for the necessary procedures, training, and logistical concerns necessary for full integration. Data collection can include audits of participation and adherence to the program as well as clinical trials to test the efficacy of in the field deployment.

The final goal of the intervention is to reduce injury and improve performance. This is performed in the final step, *Monitor and Determine Effectiveness of the Program*. Long term injury tracking (similar to the first step) is performed on populations that have been exposed to the intervention and on populations who serve as the control group. Randomized, controlled, clinical trials are employed to examine the effectiveness of the program to reduce injury. Longitudinal studies are conducted on other variables of performance to examine the impact of the intervention on performance.

The purpose of the first of two companion papers is to describe the methodology and research results through the first three steps of our injury prevention and performance model (*Injury Surveillance*, *Task and Demand Analysis*, and *Predictors of Injury and Optimal Performance*) as it is implemented and integrated within the 101st Airborne Division (Air Assault). Although this model is currently being applied to the 101st Airborne Division (Air Assault), by design it can be applied to different populations including Special Operations Forces where it may be more relevant due to the elite athlete benchmarking and the capability to individualize it to the specific needs of each Operator. Epidemiology data will be presented based on the self-reports of Soldiers tested in the Human Performance Research Center at Ft. Campbell, KY. An overview and example of a *Task and Demand Analysis* will be provided. Descriptive data across all testing methodologies (biomechanical, neuromuscular, musculoskeletal, and physiological) will be presented and will include profiling against elite athletes. Although nutrition data has been collected, it will not be reported in these two papers. The second paper will describe the methodology and research results for the *Design and Validation of Interventions*, *Program Integration and Implementation*, and *Monitor and Determine the Effectiveness of the Program*.

METHODS

Subjects

Two groups of subjects were enrolled in the study. The first group was composed of Soldiers from the 101st Air-

TABLE I Subject Demographics				
	101st Airborne Division (Air Assault)		Triathletes	
	Males (n=347)	Females (n=57)	Males (n=15)	Females (n=9)
Age (yrs)	28.1±6.6	26.7±5.5	35.7±8.5	34.7±7.1
Height (cm)	69.7±2.8	64.8±2.5	70.8±4.2	64.7±2.0
Mass (kg)	183.6±27.6	142.9±21.8	164.3±21.2	121.0±10.2

borne Division (Air Assault) in Ft. Campbell, KY. Demographic information is listed in Table 1. Soldiers were recruited via advertisement flyers and information sessions organized by the investigators of the study. A total of 404 Soldiers were tested (347 males and 57 females) across 121 different Military Occupational Specialties and all Physical Demand Rating categories.[18] To be included the study, Soldiers had to be 18 to 45 years old without any medical or musculoskeletal conditions that precluded them from full active duty. The second group included triathletes triathletes (15 males and 9 females) recruited via advertisement flyers as a benchmark for comparison to the Soldiers and for identification of suboptimal characteristics. To be included in the triathlete group, all individuals had to be healthy and free of any current medical or musculoskeletal conditions that would prevent participation in any of testing procedures. All of the triathletes were age group qualifiers for the Ironman World Championships. Triathletes were selected for the comparison group based on their multidisciplinary training and recognition as those who would have optimized many musculoskeletal and physiological characteristics such as aerobic and anaerobic endurance. Both groups were subdivided based on gender and comparisons between groups were within gender only. Human subject protection for the current study was approved by the University of Pittsburgh, Dwight D. Eisenhower Army Medical Center, Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office. All aspects of the study were explained to each Soldier and triathlete prior to voluntary participation.

Instrumentation

Injury Surveillance

Demographic, medical, nutrition and injury data

were collected using the University of Pittsburgh Military Epidemiology Database (UPitt-Med). Laboratory data were imported into the UPitt-MED. All data in the UPitt-MED were de-identified upon entry.

Task and Demand Analysis

Typically the *Task and Demand Analysis* utilizes accelerometers (ZeroPoint Technology, Johannesburg, South Africa) to examine segmental acceleration at the tibia, L5, and C7; a portable metabolic unit (OxyCon Mobile, Viasys, Yorba Linda, CA) to examine oxygen consumption and gas exchange; a heart rate monitor (Polar USA, Lake Success, NY); and an in-shoe plantar pressure system (Novel GmbH, Munich, Germany) to measure detailed foot pressure. Not all of these instruments are used during each task and demand analysis as logistical, environmental, and operational restrictions force modifications to actual testing instrumentation.

Predictors of Injury and Optimal Performance

Flexibility measurements of the shoulders, hips, knees, and ankles were assessed with a standard goniometer or digital inclinometer (Saunders Group, Chaska, MN). Strength of the shoulders, hips, knees, and back was assessed using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY). Ankle strength was assessed with a hand held dynamometer (Lafayette Instrument Company, Lafayette, IN). Balance testing data were collected with a single force plate (Kistler 9286A, Amherst, NY) at a sampling frequency of 1200 Hz. A portable metabolic system (OxyCon Mobile, Viasys, Yorba Linda, CA) was used to assess oxygen consumption during a maximal oxygen uptake test. Blood lactate was assessed with a portable lactate analyzer (Arkray, Inc, Kyoto, Japan). A heart rate monitor (Polar USA, Lake Success, NY) was worn by the subject during testing. Anaerobic power was measured utilizing the Velotron cycling ergometer (RacerMate, Inc, Seattle, WA). Body composition was assessed with The Bod Pod Body Composition System (Life Measurement Instruments, Concord, CA) through air displacement plethysmography. Raw coordinate data for the biomechanical analysis of lower extremity performance and functional testing was collected with the six high-speed cameras (Vicon, Centennial, CO). Ground reaction forces were measured using two Kistler force plates (Kistler Instrument Corp., Amherst, NY).

Procedures

All testing of Soldiers of the 101st was performed in the University of Pittsburgh Human Performance Research Center at Ft. Campbell, KY. Subjects who were part of the athlete comparison group were tested at the Neuromuscular Research Laboratory at the University of Pittsburgh (Pittsburgh, PA). Testing occurred over two days (approximately two hours each day) separated by approximately one week. After informed written consent was obtained, each subject was asked to provide a detailed medical history and a history of all musculoskeletal injuries. Subjects were also given a detailed diet history including a food frequency and 24 hour recall to be filled out prior to returning on the second day (data not reported in the current manuscript).

Injury Surveillance

A detailed self-report of injury was obtained from participants in the study. Operational definitions of data (anatomic location of injury, type of injury, activity when injury occurred, etc.) were discussed and defined in meetings of the research group prior to the initiation of the study, in order to ensure validity and consistency of data.

Task and Demand Analysis

A total of seven task and demand analyses were performed to examine different physical training, tactical training, and other functional tasks that Soldiers have to perform as part of their regular duties. The activities chosen were based on consultation with the Division Surgeon and Division Command. They included the following:

Task Analysis
1. Drop exit from a vehicle
2. Rope climb (up and down)
3. Loading and unloading equipment from a vehicle
4. Night training – landing from a jump with low light conditions

Demand Analysis (Obstacle Course)
1. Eagle First Responder Course
2. Air Assault O-Course
3. Joint Readiness Training Center activities

The results of these analyses were utilized to develop the procedures examining *Predictors of Injury and Optimal Performance* and the exercises and activities included in the *Design and Validation of Interventions* (See Companion Paper). Additional tasks were examined based on the potential for injury. Data were collected in the field. The actual data collection procedures and equipment utilized was dependent on the specific task, environmental conditions, and the capability to collect data with minimal interference to training and the Soldier. For sake of brevity, a description of two examples of *Task and Demand Analysis* are provided.

Qualitative observations (See Figure 2 for task analysis and Figure 3 for demand analysis) were collected on one Soldier exiting a vehicle (task analysis) and quantitative data was collected on one Soldier during the 101st Airborne Division (Air Assault) Obstacle Course (demand analysis). The qualitative observations included musculoskeletal, neuromuscular, and biomechanical demands and an examination of the movement patterns, forces, velocities, joint angles, and planes of motion which identifies the muscles and other parts of the body used to execute the specific joint and whole body actions. The O-course was designed to evaluate Soldiers' ability to negotiate and maneuver obstacles without fear of height. There are nine obstacles that include: "tough one"

Figure 2: *Task analysis –*
Field observation with laboratory simulated testing

Figure 3: *Demand analysis –*
Field testing as observed on the O-Course

(rope climb), incline wall, "low belly over" (jump onto beam, forward flip, and land on the ground), "confidence climb" (log/beam climb, walk across beam, climb down), six vaults, swing stop and jump on a rope, low belly crawl (not performed due to equipment considerations), high step over, and "weaver" (over and under beams suspended in the air). One male Soldier (Age: 20 years; Height: 68 inches; Weight: 161 pounds) was observed during the O-Course and outfitted with the portable metabolic equipment and the heart rate monitor. The Soldier was wearing his army combat uniform and boots. For the purpose of task and demand analysis, the Soldier was asked to complete the O-course twice with an 8 minute 45 second rest between each run. The data (VO_2) were monitored during the rest period until it returned to resting value prior to the beginning of the O-course. Data were collected for a total of 24 minutes and 15 seconds while the subject was engaged in the O-Course training.

Predictors of Injury and Optimal Performance

Passive shoulder, hip, and knee motion were measured passively using the methods described by Norkin and White.[19] Passive measurements included hip flexion and extension, knee flexion, and triplanar shoulder motion. Posterior shoulder tightness was measured in a supine position but was based on the description by Tyler et al.[20, 21] Hamstring flexibility was measured in supine using the active knee extension test.[22] Active dorsiflexion was measured with the knee straight as described by Norkin and White.[19] Torso flexibility was measured in a seated position utilizing the torso rotation attachment of Biodex Multi-Joint System 3 Pro based on a previous study.[23]

Bilateral shoulder internal/external rotation, hip abduction/adduction, knee flexion/extension, and torso rotation strength were assessed with the Biodex System III Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc., Shirley, NY). All torque values were adjusted for gravity by the Biodex Advantage Software v.3.2 (Biodex Medical Inc., Shirley, NY) and calibrated according to the specifications outlined in the manufacturer's service manual. For each test, the subjects were provided details of the procedure, stabilized according to the manufacturer's guidelines, given three practice trials (three sub-maximal contractions (50% effort) followed by three maximal contractions) to ensure patient understanding and familiarity. A rest period of at least 60 degree/seconds was given prior to each strength test. Reciprocal concentric isokinetic shoulder internal/external, knee flexion/extension, and left/right torso rotation strength was tested at 60°/second (5 repetitions). Isometric hip abductor/adductor strength was tested in the side-lying, hip neutral position while they performed three, five-second alternating hip abduction and adduction isometric contractions. Ankle inversion/eversion strength was measured with a handheld dynamometer. All ankle strength tests were performed in a seated position based on traditional manual muscle strength testing hand placement. Three trials for each movement were collected and averaged.

Balance testing was assessed according to Goldie et al.,[24, 25] using a single force plate sampling at a frequency of 100Hz. Subjects performed three trials (10 seconds each) of a single-leg standing balance test (barefooted) for each leg under eyes open and eyes closed conditions. Subjects were asked to remain as still as possible with feet shoulder width apart and hands on hips.

Subjects performed an incremental ramped protocol to determine maximal oxygen consumption and lactate threshold. Subjects were fitted with the portable metabolic system and a heart rate monitor. The protocol consisted of a five-minute warm-up; an initial three-minute workload at 0% grade (starting speed for each Soldier was 70% of the two-mile run time during the Soldier's most recent Army Physical Fitness Test); and followed by an incline increase of 2.5% (grade) every three minutes while the speed remained constant.[26] Prior to each change in incline, a finger stick for a blood sample was taken to assess blood lactate levels. Subjects were instructed to continue running until exhaustion (defined as the inability to continue the test due to cardiovascular or peripheral inhibition). Heart rate and VO_2 were monitored continuously throughout the test. The specific variables analyzed included relative maximal oxygen uptake (VO_{2max}: ml/kg/min), heart rate max (HR_{max}) in beats per minute (bpm), respiratory exchange ratio (RER: VCO_2/VO_2), VO_2 at lactate threshold (ml/kg/min), percent

of VO_{2max} at lactate threshold (%VO_{2max}), heart rate at lactate threshold (bpm), and percent of heart rate max at lactate threshold (%HR_{max}).

Anaerobic power and capacity were measured with an electromagnetic cycling ergometer utilizing the Wingate protocol (Racermate Inc, Seattle, WA). Proper seat and handlebar adjustments were made before the subject's feet were secured to the pedals, and a warm-up cycle at a self-selected cadence was initiated at 125 Watts. Subjects underwent a 50-second cycling protocol. After fifteen seconds of maintaining 100 RPM at 125 Watts, the participant was instructed to sprint and generate as much speed prior to the initiation of the normalized resistance. The participant continued to sprint and maintained as much speed as possible during the remainder of the 30s resistance duration. A standardized braking torque of 9% body weight was utilized for males and 7.5% body weight was utilized for females.[27,28] Anaerobic power was reported as the peak watts normalized to body weight produced during the first five seconds of the test, and anaerobic capacity was reported as the average watts normalized to body weight produced during the entire 30-seconds (W/kg).

The Bod Pod® Body Composition System (Life Measurement Instruments, Concord, CA) was used to measure body composition. The Bod Pod® utilizes air-displacement plethysmography to measure body volume and calculate body density. The system underwent a standard calibration utilizing a 50.683 L calibration cylinder, and an additional two-point calibration prior to each test. Subject wore spandex shorts and swim caps. Body volume was measured until two consistent measurements were achieved. Predicted lung volume and an appropriate densitometry equation were used to calculate percent body fat (%BF). The Bod Pod Body Composition System was utilized to calculate body mass and percent of fat and fat free mass.

A biomechanical analysis was performed while subjects performed an athletic task (stop jump task) and a functional landing task (drop landing task). Subjects were fitted with sixteen retro-reflective markers on anatomical land marks according to Vicon's Plug-in-Gait (Vicon, Centennial, CO). Subjects' height, mass, ankle width, knee width, and leg length were entered into the operating software (Nexus v1.3, Vicon, Centennial, CO) prior to collecting a static calibration trial with the participant standing in anatomical position. After completing the static calibration trial, participants were instructed to perform the stop jump task – a standing broad jump from a normalized distance of 40% of the participant's height followed immediately (after landing on the force plates) by a maximal effort vertical jump.[25] For the drop landing task, subjects were instructed to drop from a standardized height of 20 inches and land on the force plates. Although this height is less than that observed during the task analysis of exiting a vehicle, it was deemed the safest height appropriate for the large range of subjects tested in the current study. Additionally, the protective mechanisms studied in are the same regardless of height.

Data Reduction
Injury Surveillance

Self-reported data about injuries in study participants were entered into UPitt-MED by athletic trainers at the Ft. Campbell laboratory, in the presence of the study participant. The Pitt-MED is designed to facilitate an epidemiological analysis of the factors associated with performance, injuries, disabilities and tactical readiness. Tables in the database store data about physiological measures of strength, endurance, cardiovascular fitness; and musculoskeletal (strength, flexibility and balance), biomechanical, anthropometric and demographic data; in addition to the data related to medical events and injury. A detailed nutrition history was completed for each subject including a 24 hour diet recall, food frequency questionnaire and dietary supplement survey (not reported in the current manuscript).

Task and Demand Analysis

Quantitative variables calculated for the specific *Task and Demand Analysis* performed and presented in the current manuscript included the minimum, maximum, and average heart rate; breathing frequency; oxygen consumption; and respiratory exchange ratio. Time spent exercising at or above the anaerobic threshold was estimated using laboratory determined VO_2 and lactate threshold data. A description of the tasks performed including the perceived musculoskeletal, neuromuscular, and biomechanical demands is presented as part of the qualitative analysis.

Predictors of Injury and Optimal Performance

All flexibility and range of motion measures are presented as an average of three trials. Strength measures are reported as an average of three trials and then normalized to each subject's individual body weight (tests using the Biodex System III Multi-Joint Testing and Rehabilitation System) or mass (hand held dynamometer). The standard deviation for the ground reaction forces for each direction (anterior-posterior, medial-lateral, and vertical) was calculated during the 10-second trial and then averaged across all three trials for both balance testing conditions.

For the aerobic test, a maximal test was verified by identifying one of the following physiological achievements: HR at or above age predicted max (220 – age), absolute oxygen uptake values not rising despite increase in intensity, blood lactate at or above 8mmol/L, respiratory exchange ratio (RER)

TABLE 2 Number of Injuries per Subject		
Number of Injuries	Number of Subjects	Relative Frequency (%)
0	174	72.2
1	45	18.7
2	17	7.1
3	2	0.8
4	2	0.8
6	1	0.4
Total subjects	241	100.00%

at or above 1.1, or volitional fatigue. The metabolic data were filtered with a 15-second moving window to reduce the overall breath-by-breath data points. The VO_2 data were then plotted across time to identify the highest consecutive values over the time period of one minute during the test. Lactate values for

TABLE 3
Anatomic Sub-Location of the Injuries

Anatomic Location	Sub-Location	Number of Injuries	Percent of Injuries
Lower Extremity	Foot and Toes	10	10.1
	Thigh	8	8.1
	Lower Leg	12	12.1
	Hip	1	1.0
	Knee	13	13.1
	Ankle	18	18.2
Upper Extremity	Hand and Fingers	3	3.0
	Upper Arm	2	2.0
	Shoulder	11	11.1
	Wrist	4	4.0
Spine	Cervical	1	1.0
	Thoracic	1	1.0
	Lumbopelvic	7	7.1
	Other	3	3.0
Head/Face		5	5.1
Total		99	99.9%*

*Percents do not add up to 100.0 due to rounding

TABLE 4
Types of Injuries

Type of injury		Number of injuries	Percent of injuries
Concussion		4	4.0
Ear injury		1	1.0
Fracture	Upper Extremity	2	2.0
	Lower Extremity	3	3.0
Sprain	Upper Extremity	6	6.1
	Lower Extremity	16	16.2
Strain	Spine	5	5.1
	Upper Extremity	4	4.0
	Lower Extremity	7	7.1
Dislocation – Lower extremity		1	1.0
Chondromalacia/Patellofemoral Pain		4	4.0
ITB		6	6.1
Plantar Fasciitis		7	7.1
Back pain/spasm		2	2.0
Other pain		2	2.0
Tendonitis – Lower Extremity		2	2.0
Nerve injury – Upper extremity		1	1.0
Shin Splints		3	3.0
Disc injury		1	1.0
Contusion		2	2.0
Subluxation – Lower extremity		1	1.0
Reported "overuse"		1	1.0
Shoulder separation		1	1.0
Meniscal		3	3.0
Shoulder impingement		2	2.0
Unspecified injury type		9	9.1
Others		3	3.0
Total		99	99.8%*

*Percents do not add up to 100.0 due to rounding

each stage were plotted across time to identify lactate threshold. An inflection point was identified in the lactate plot as the point at which levels began rising greater than or equal to 1mmol/L between stages. The oxygen uptake and heart rate data points corresponding with the point in time of the lactate inflection

point were used to calculate percent of VO_{2max} and HR_{max} at lactate threshold. Anaerobic power, anaerobic capacity, and fatigue index are automatically generated by the Wingate software upon completion of the test. Anaerobic power output is calculated as the peak within five seconds of the test starting while anaerobic capacity is calculated as the mean power output of the 30s duration. Anaerobic power and capacity are reported as relative (W/kg) variables. Fatigue index is calculated as the average rate of change in power across the 30s test. Body composition is reported in percent body fat mass based on total body volume utilizing the subject's body mass and race/gender appropriate density formulas.

Data processing for the biomechanical analysis of the two different lower extremity tasks has been reported elsewhere.[30] The variables analyzed for both tasks included the maximum knee and hip flexion angle; knee and hip flexion at initial contact; the maximum knee valgus/varus angle; the knee valgus/varus angle at initial contact; and the peak vertical ground reaction force.

Statistical Analysis

All data analysis was performed with de-identified data. The description of *Injury Surveillance* data included a calculation of the average number of injuries per person; relative frequencies of injuries by anatomic location; cause of injury; activity when injury occurred; and type of injury. The minimum, maximum, and average for each of the variables collected during the *Task and Demand Analysis* are presented in table format for each portion of the activity analyzed. The qualitative description of the task relative to the biomechanical and musculoskeletal demands is presented. Means and standard deviations for each of the *Predictors of Injury and Optimal Performance* collected are calculated for each group (Soldiers and triathletes) within gender. Comparisons between the Soldier group and triathlete group were performed within gender utilizing independent t-tests with an alpha level of 0.05 chosen a priori. Statistical analysis was done using SPSS 17.0 (SPSS Inc., Chicago IL).

RESULTS
Injury Surveillance

Self-reported injury data for the one year prior to testing was available for 241 Soldiers. There were 13 bilateral injuries, which have been counted twice in this report. A total of 99 injuries were reported. One hundred seventy-four subjects (174/241, 72.2%) did not report any injuries during a one year period. The average numbers of injuries reported per subject during a one year period were 0.41. Forty-five Army personnel (45/241, 18.7%) had reported one injury, and seventeen (17/241, 7.1%) had reported two injuries, during a one year period (see Table 2). Figure 4 provides an overview of the general anatomic location for each of the injuries with a more specific breakdown presented in Table 3. The majority of injuries (62.6%) occurred in the lower extremity. The ankle joint (18.2%) and

Figure 4: *Anatomic location of the injuries*

<table>
<tr><td colspan="3" align="center">TABLE 5
Cause of Injuries</td></tr>
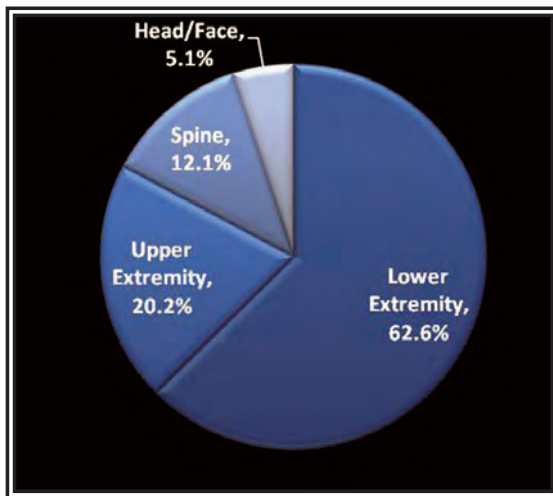<tr><th>Cause of injury</th><th>Number of injuries</th><th>Percent of injuries</th></tr>
<tr><td>Running</td><td>34</td><td>34.3</td></tr>
<tr><td>Fall</td><td>8</td><td>8.1</td></tr>
<tr><td>Direct Trauma</td><td>8</td><td>8.1</td></tr>
<tr><td>Lifting</td><td>8</td><td>8.1</td></tr>
<tr><td>Landing</td><td>4</td><td>4</td></tr>
<tr><td>Twist/Turn/Slip (no fall)</td><td>2</td><td>2</td></tr>
<tr><td>Marching</td><td>2</td><td>2</td></tr>
<tr><td>Pulling</td><td>2</td><td>2</td></tr>
<tr><td>Cutting</td><td>1</td><td>1</td></tr>
<tr><td>Planting</td><td>1</td><td>1</td></tr>
<tr><td>Other</td><td>3</td><td>3</td></tr>
<tr><td>Not specified</td><td>15</td><td>15.2</td></tr>
<tr><td>Recreational activity/ sports related (cause not specified)</td><td>9</td><td>9.1</td></tr>
<tr><td>Training related (cause not specified)</td><td>2</td><td>2</td></tr>
<tr><td>Total</td><td>99</td><td>99.9%*</td></tr>
</table>

*Percents do not add up to 100.0 due to rounding

knee joint (13.1%) were the two most commonly injured joints. The most common specified type of injury (see Table 4) was a sprain of the lower extremity (16.2%), followed by strains of the lower extremity and plantar fasciitis (7.1% each). Ankle sprain was the most common injury, followed by plantar fasciitis, and then strain of the spine. The cause of injuries is presented in Table 5. Running was the most common cause of injury (34.3%). Recreational activity/sports related causes were the second most common cause (9.1%). Nearly half of all the injuries (48.5%) occurred during training (physical training, tactical training or unspecified training), and 15.2% of injuries occurred during recreational activity/sports activity. Some other activities during injury included combat (6.1%) and motor vehicular accident (4.0%). Activity during injury was not reported in 14.1% of injuries.(Figure 5).

Task and Demand Analysis
Task Analysis

      The following are the qualitative observations of exiting a vehicle. The task involves both a vertical and horizontal component. The vertical component involves the displacement of the body caused by gravity. As the Soldier drops off of the tailgate, from an approximate tailgate height of 1m, gravity accelerates him down to the ground. The Soldier's landing would exert a considerable amount of force to stop the vertical movement of his body. During the landing the Soldier flexes his hip and knee to reduce the impact caused by the vertical force. Additional load (equipment carried) would increase the magnitude of the force during landing. The horizontal component of this task requires the Soldier to neutralize his horizontal momentum and regain balance. During the landing the ground exerted a posterior force which would have to be neutralized by dynamic joint restraints.

Demand Analysis

      The purpose of the demand analysis was to measure and characterize the metabolic and physiologic demands of spe-
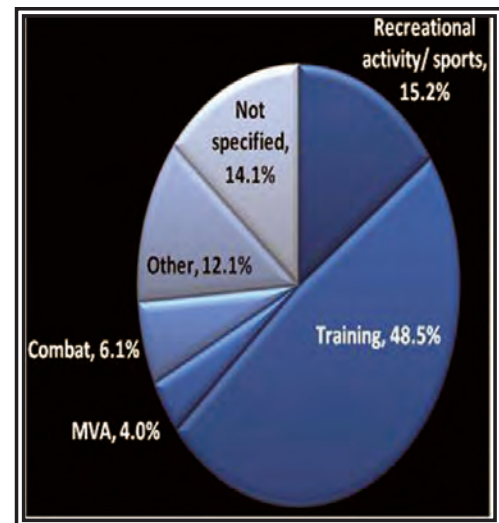
Figure 5: *Activity when injury occurred*

cific military tasks including, energy expenditure, aerobic and anaerobic energy system usage and substrate utilization. Data from the laboratory maximal oxygen consumption test were utilized to evaluate the metabolic and physiologic responses of the O-Course training (Table 6). The O-Course training lasted 24 minutes and 15 seconds including an eight minute and 45 second rest between runs. The data revealed the O-course is a high intensity activity (Table 7). Of the 15 minutes and 30 seconds total O-Course run time, ~196kcals were expended, or ~12kcal per minute (10 METs). The Soldier completed the first run in six minutes and 35 seconds, of which approximately four minutes, or ~62%, was spent at or above anaerobic threshold. The second run was completed in eight minutes and 55 seconds, of which approximately one minute, or ~11%, was spent at or above anaerobic threshold. Of the total O-Course run time (15:30), approximately five minutes (32% of total time) involved training at or above the anaerobic threshold (laboratory determined lactate threshold) and five minutes and 30 seconds

(35% of total run time) involved training at or above 60% laboratory determined VO2max, but less than the lactate threshold, indicating high metabolic demands during the O-course training for both aerobic and anaerobic energy pathways (Figure 6). Heart rate averaged 173.6 beats per minute (87% HRmax) and peaked at 195.6 beats per min (98% HRmax) during the first run, and averaged 181.8 beats per minute (91% HRmax) and peaked at 197.6 beats per minute (99% HRmax) during the second run. Thus improving performance in training tasks similar to those tasks performed in the O-course requires adapting and enhancing both energy systems to optimize physical performance.

Predictors of Injury and Optimal Performance

The range of motion and flexibility data are presented in Table 8. A total of 24 comparisons were made between Soldiers and triathletes. Male Soldiers of the 101st demonstrated significantly greater right and left shoulder flexion; left shoul-
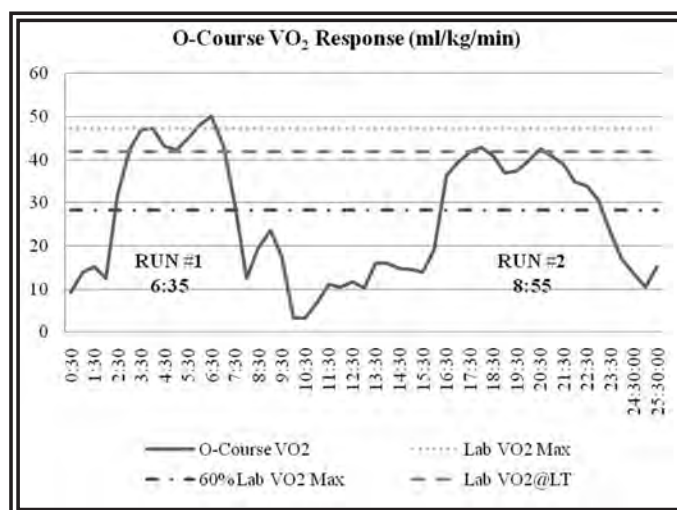

Figure 6: *VO2 response during the O-Course*

TABLE 6					
Laboratory Maximal Oxygen Uptake Data: O-Course Demand Subject (N=1)					
VO₂Max* (ml/kg/min)	HR Max* (bpm)	RER Max* (VCO2/VO2)	VO₂ @ Lactate Threshold (ml/kg/min)	% VO₂ max at Lactate Threshold	Lactate at Lactate Threshold (mmol/L)
48.7	197.5	1.0	41.9	86.1	3.8

*Laboratory maximum values calculated by averaging the highest consecutive values over a one-minute period during the laboratory test.

der extension; and right and left shoulder abduction than male triathletes. Male triathletes demonstrated significantly less posterior shoulder tightness for both the right and left shoulder as well as significantly greater right and left hip flexion. Male Soldiers of the 101st had significantly greater right and left hip extension and right and left calf flexibility. The comparisons between female Soldiers of the 101st and female triathletes revealed significant differences across nine of the flexibility and range of motion measures. Female 101st Soldiers had significantly greater right and left shoulder abduction but had more posterior shoulder tightness bilaterally than female triathletes. Female 101st Soldiers also had significantly greater knee flexion range of motion and calf flexibility. Right torso rotation was significantly greater in female triathletes compared to female 101st Soldiers.

Strength data are presented in Table 9. A total of 20 comparisons were made between Soldiers and triathletes. Male triathletes had significantly stronger left shoulder internal and external rotation; left knee flexion; and greater right knee flexion/extension strength ratio compared to male 101st Soldiers. Male 101st Soldiers had significantly stronger right and left ankle inversion and ankle eversion strength than male triathletes. Female triathletes had significantly stronger left shoulder internal rotation; right and left shoulder external rotation; right and left knee flexion; and left knee extension strength than female 101st Soldiers.

The balance data are presented in Table 10. Six comparisons were made for each of the two balance conditions tested (eyes open and eyes closed). The statistical analysis revealed only one significant difference between the 101st Soldiers and the triathletes, male 101st Soldiers had significantly lower (better) left leg medial/lateral ground reaction forces standard deviation (GRF SD) than male triathletes.

The physiology data is presented in Table 11. A total of 10 comparisons were made. Despite no significant difference observed in body mass index, male triathletes had significantly less body fat than male 101st Soldiers. Male triathletes also had greater mean anaerobic power, VO₂max, VO₂ at lactate threshold, and percent VO₂ at lactate threshold. Female triathletes had significantly lower body mass index and body fat percentage than female 101st Soldiers. Female triathletes also had significantly greater peak anaerobic power, mean anaerobic power, VO₂max, VO₂ at lactate threshold, percent VO₂ at lactate threshold, and heart rate at lactate threshold than female 101st Soldiers.

The biomechanical data for the stop-jump task and the vertical drop landing task are presented in Table 12 and Table 13 respectively. A total of 12 comparisons were made for each task.

TABLE 7												
Physiological Data During *O-Course Demand Analysis*												
	TOTAL O-Course				Run #1 (6 min 35 sec)				Run #2 (8 min 55 sec)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Heart Rate (beats/min)	169.6	23.3	124.4	197.6	173.6	28.5	124.4	195.6	181.8	20.2	131.4	197.6
Breathing Frequency (breaths/min)	41.2	12.6	3.0	58.2	41.7	11.2	23.1	53.2	49.6	8.0	34.1	58.2
VO₂ (ml/kg/min)	26.7	14.4	3.2	50.1	34.4	15.8	9.1	50.1	32.8	10.1	13.5	42.8
Respiratory Exchange Ratio (VCO₂/VO₂)	0.9	0.1	0.7	1.2	0.9	0.1	0.8	1.0	0.9	0.1	0.9	1.1

TABLE 8
Range of Motion and Flexibility (Degrees)

	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Shoulder Flexion[a]	187.2	7.3	177.4	10.9	p<0.001	188.0	14.7	188.0	10.7	1.0000
Left Shoulder Flexion[a]	187.8	7.3	176.7	10.7	p<0.001	186.6	17.2	188.7	11.5	0.7315
Right Shoulder Extension	70.8	13.3	69.2	8.5	0.6448	83.6	9.8	80.4	8.4	0.3585
Left Shoulder Extension[a]	72.6	13.0	71.4	9.2	p<0.001	85.0	10.0	82.4	6.3	0.4540
Right Shoulder Abduction[a,b]	206.1	9.5	194.1	11.3	p<0.001	211.8	8.8	198.1	18.3	0.0024
Left Shoulder Abduction	205.4	10.3	193.0	10.0	p<0.001	209.7	6.9	201.4	10.8	0.0071
Right Shoulder External Rotation	109.9	13.2	111.8	7.1	0.5803	120.3	16.8	123.3	12.2	0.6095
Left Shoulder External Rotation	104.2	12.0	109.1	8.6	0.1190	113.9	14.9	117.5	13.6	0.4985
Right Shoulder Internal Rotation	58.5	10.6	54.3	9.1	0.1320	59.9	11.6	62.9	16.4	0.4991
Left Shoulder Internal Rotation	66.1	13.2	62.4	9.7	0.2843	66.0	14.8	74.9	13.6	0.0953
Right Shoulder Posterior Shoulder Tightness[a,b]	102.4	9.7	109.7	7.0	0.0043	108.7	7.5	121.2	10.8	p<0.001
Left Shoulder Posterior Shoulder Tightness[a,b]	104.4	9.4	110.9	7.6	0.0089	110.5	6.7	122.8	11.2	p<0.001
Right Knee Flexion[b]	143.1	6.6	141.5	6.9	0.3729	148.5	5.9	141.3	8.0	0.0046
Left Knee Flexion[b]	142.3	7.1	139.2	6.3	0.1051	147.5	5.9	141.4	7.2	0.0122
Right Active Knee Extension	18.8	9.4	14.5	11.4	0.0867	11.4	7.9	12.3	11.5	0.7671
Left Active Knee Extension	17.6	9.9	14.4	9.6	0.2208	9.6	7.3	12.6	11.6	0.2977
Right Hip Flexion[a]	133.1	7.1	138.2	5.7	0.0075	135.8	16.9	141.3	10.4	0.3590
Left Hip Flexion	133.4	7.2	136.8	5.7	0.0869	135.8	16.3	139.0	8.2	0.5736
Right Hip Extension[a]	29.3	8.0	21	8.5	p<0.001	33.9	7.3	35.5	9.4	0.5598
Left Hip Extension[a]	30.0	8.2	20.7	6.3	p<0.001	34.2	7.1	36.7	7.8	0.3368
Right Calf Flexibility[a,b]	15.9	6.8	12.0	5.9	0.0296	15.1	5.4	10.7	5.5	0.0268
Left Calf Flexibility[a,b]	16.1	6.8	11.7	5.6	0.0140	15.1	6.1	10.1	6.3	0.0262
Right Torso Rotation[b]	70.4	11.0	71.8	9.1	0.6276	72.7	11.5	81.6	12.0	0.0357
Left Torso Rotation	65.8	10.6	69.7	11.9	0.1662	68.3	11.5	75.9	11.1	0.0689

[a]Significant difference between male Soldiers and Triathletes

[b]Significant difference between female Soldiers and Triathletes

TABLE 9
Strength

	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Shoulder Internal Rotation (%BW)	59.64	15.54	64.30	9.67	0.2455	36.28	8.45	40.83	8.83	0.1404
Left Shoulder Internal Rotation (%BW)[a,b]	54.65	15.94	65.52	13.56	0.0094	33.97	8.14	42.99	8.18	0.0030
Right Shoulder External Rotation (%BW)[b]	42.09	8.75	46.49	6.92	0.0570	29.94	5.14	34.89	6.71	0.0124
Left Shoulder External Rotation (%BW)[a,b]	37.94	7.82	44.48	7.26	0.0014	26.99	4.62	32.71	7.45	0.0025
Right Shoulder Internal/External Strength Ratio	0.73	0.14	0.73	0.10	1.0000	0.85	0.20	0.87	0.15	0.7752
Left Shoulder Internal/External Strength Ratio	0.72	0.15	0.69	0.11	0.4448	0.82	0.17	0.76	0.10	0.3084
Right Knee Flexion (%BW)[b]	114.81	27.14	128.00	22.63	0.0648	92.98	21.05	115.47	15.44	0.0032
Left Knee Flexion (%BW)[a,b]	111.72	26.34	128.50	23.23	0.0158	88.82	20.80	113.96	14.88	0.0009
Right Knee Extension (%BW)	236.12	48.03	242.09	50.38	0.6387	191.30	37.16	216.53	21.68	0.0525
Left Knee Extension (%BW)[b]	226.02	44.56	241.31	42.89	0.1938	178.18	38.19	211.38	34.71	0.0170
Right Knee Flexion/Extension Strength Ratio[a]	0.49	0.09	0.54	0.10	0.0369	0.49	0.06	0.53	0.04	0.0585
Left Knee Flexion/Extension Strength Ratio	0.50	0.09	0.53	0.05	0.2011	0.50	0.08	0.54	0.05	0.1519
Right Ankle Inversion Strength (%BW)[a,b]	34.43	7.22	23.60	3.72	p<0.001	24.90	6.70	19.18	2.23	0.0141
Left Ankle Inversion Strength (%BW)[a,b]	33.21	6.86	23.15	4.76	p<0.001	24.08	6.16	19.01	3.23	0.0190
Right Ankle Eversion Strength (%BW)[a,b]	30.49	6.71	21.52	2.34	p<0.001	22.25	5.93	16.96	1.58	0.0103
Left Ankle Eversion Strength (%BW)[a,b]	30.99	6.50	21.61	3.48	p<0.001	22.61	6.00	18.16	4.24	0.0365
Right Ankle Inversion/Eversion Strength Ratio	1.15	0.19	1.10	0.12	0.4199	1.13	0.21	1.13	0.11	1.0000
Left Ankle Inversion/Eversion Strength Ratio	1.09	0.18	1.08	0.20	0.8342	1.08	0.20	1.08	0.22	1.0000
Right Torso Rotation Strength (%BW)	145.12	33.05	151.51	25.94	0.4607	110.49	32.89	118.53	24.59	0.4858
Left Torso Rotation Strength (%BW)	144.82	32.80	154.57	30.90	0.2596	111.62	28.02	114.85	25.74	0.7466

[a]Significant difference between male Soldiers and Triathletes

[b]Significant difference between female Soldiers and Triathletes

TABLE 10 Balance (SD)	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Leg Eyes Open - Anterior/Posterior GRF	2.78	0.86	2.84	0.94	0.7938	2.02	0.55	2.32	1.22	0.2291
Left Leg Eyes Open - Anterior/Posterior GRF	2.79	1.01	3.26	1.06	0.1282	2.04	0.51	1.79	0.53	0.1828
Right Leg Eyes Open - Medial/Lateral GRF	3.44	1.16	3.88	1.52	0.1613	2.43	0.96	2.60	2.08	0.7068
Left Leg Eyes Open - Medial/Lateral GRF	3.43	1.46	4.09	1.54	0.0905	2.40	0.75	2.08	0.81	0.2481
Right Leg Eyes Open - Vertical GRF	4.65	2.19	5.26	2.14	0.2942	3.18	1.34	3.78	2.08	0.2618
Left Leg Eyes Open - Vertical GRF	4.77	2.74	5.87	2.79	0.1318	3.40	1.34	3.29	1.29	0.8203
Right Leg Eyes Closed - Anterior/Posterior GRF	6.44	2.66	6.84	2.14	0.5659	4.43	1.77	5.82	2.90	0.0552
Left Leg Eyes Closed - Anterior/Posterior GRF	6.76	3.40	7.59	4.16	0.3643	4.81	1.55	6.00	2.83	0.0699
Right Leg Eyes Closed - Medial/Lateral GRF	10.11	4.57	11.10	4.93	0.4169	6.15	2.39	7.59	6.28	0.2210
Left Leg Eyes Closed - Medial/Lateral GRF[a]	9.93	4.79	12.80	7.26	0.0295	6.98	2.41	7.92	6.40	0.4290
Right Leg Eyes Closed - Vertical GRF	14.53	12.22	13.82	6.37	0.8237	8.61	5.52	10.13	5.72	0.4517
Left Leg Eyes Closeed - Vertical GRF	14.75	11.94	18.88	14.53	0.1988	10.95	9.23	10.72	5.67	0.9428

[a]Significant difference between male Soldiers and Triathletes
[b]Significant difference between female Soldiers and Triathletes

TABLE 11 Physiology	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Body Mass Index (BMI)[b]	23.0	2.9	23.1	2.3	0.8953	23.96	3.09	20.33	0.97	p<0.001
Body Fat %[a,b]	20.1	7.5	12.3	4.4	p<0.001	26.72	5.70	17.37	4.38	p<0.001
Peak Anaerobic Power (Watts)[b]	13.3	2.1	13.8	1.0	0.3601	9.49	1.66	11.92	1.43	p<0.001
Mean Anaerobic Power (Watts)[a,b]	7.8	1.0	9.3	0.7	p<0.001	6.13	0.75	8.37	0.80	p<0.001
VO2 Max (mL/min/kg)[a,b]	47.5	7.6	69.8	7.3	p<0.001	40.29	5.37	61.15	5.44	p<0.001
VO2 at Lactate Threshold (mL/min/kg)[a,b]	39.0	7.0	58.2	7.3	p<0.001	33.52	5.49	54.03	5.91	p<0.001
VO2 % at Lactate Theshold	81.8	10.3	83.7	8.5	0.4826	82.16	13.97	88.38	6.57	0.1968
HR Max[b]	188.6	14.2	182.7	11.3	0.1139	188.89	9.59	179.89	11.41	0.0139
HR at Lactate Threshold	169.4	15.3	167.2	12.2	0.5837	171.40	12.09	168.44	13.33	0.5057
HR % at Lactate Threshold	89.6	7.2	91.5	3.9	0.3113	90.96	5.18	93.62	3.77	0.1465

[a]Significant difference between male Soldiers and Triathletes
[b]Significant difference between female Soldiers and Triathletes

For the stop-jump task, male triathletes landed with greater hip flexion at initial contact bilaterally; less left hip abduction at initial contact; and greater left knee flexion at initial contact than male 101st Soldiers. Male 101st Soldiers had greater maximum knee flexion angle bilaterally than male triathletes. There were only two significant differences between female 101st Soldiers and female triathletes during the stop-jump task. Female triathletes landed with significantly greater knee flexion at initial contact bilaterally than female 101st Soldiers. There were no observed significant differences for either gender during the vertical drop landing.

DISCUSSION

The purpose of this paper (Part 1 of two companion papers) was to describe the methodology and research results related to the first three steps of our injury prevention and performance optimization model. These steps included *Injury Surveillance*, *Task and Demand Analysis*, and *Predictors of Injury and Optimal Performance*. Data was presented based on self-reported injury history; quality and quantitative analysis of tasks and activities that Soldiers have to perform as part of their duties; and on musculoskeletal, physiological, and biomechanical testing in the laboratory. The injury epidemiology data revealed a history of injury that is consistent with previous studies; injuries that are primarily occurring during physical and tactical training; and injuries that are potentially preventable through interventions. The qualitative and quantitative analysis of the task and demand analyses demonstrated that a biomechanical analysis of a vertical drop landing as well as anaerobic ca-

	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Hip Flexion at Initial Contact (Degrees)[a]	42.4	11.3	51.1	15.6	0.0049	45.9	11.7	49.6	11.7	0.3869
Left Hip Flexion at Initial Contact (Degrees)[a]	43.6	11.1	54.6	17.2	p<0.001	46.1	12.5	50.2	11.2	0.3628
Right Hip Abduction at Initial Contact (Degrees)	-3.7	4.1	-2.9	4.2	0.4637	-2.6	3.5	-2.6	3.9	1.0000
Left Hip Abduction at Initial Contact (Degrees)[a]	-3.7	4.0	-1.3	4.1	0.0248	-2.5	5.1	-5.0	3.0	0.1613
Right Knee Flexion at Initial Contct (Degrees)[b]	25.8	8.0	28.2	13.5	0.2813	26.8	7.7	33.7	7.8	0.0167
Left Knee Flexion at Initial Contct (Degrees)[a,b]	27.5	8.4	34.5	11.5	0.0024	27.4	8.2	34.9	8.2	0.0145
Right Knee Valgus/Varus at Initial Contact (Degrees)	4.6	6.3	5.9	5.3	0.4344	-1.4	5.6	-4.6	6.7	0.1318
Left Knee Valgus/Varus at Initial Contact (Degrees)	4.7	6.8	5.8	8.8	0.5498	-1.4	6.0	-2.6	3.7	0.5658
Right Knee Maximum Flexion (Degrees)[a]	92.0	14.0	77.7	18.0	p<0.001	89.4	13.4	89.6	9.6	0.9661
Left Knee Maximum Flexion (Degrees)[a]	92.1	13.9	81.6	11.1	0.0044	88.2	13.7	92.2	11.7	0.4151
Right Peak Vertical Ground Reaction Force (% BW)	205.3	56.3	208.4	47.2	0.8347	201.6	63.9	198.6	65.3	0.8978
Left Peak Vertical Ground Reaction Force (% BW)	195.7	54.3	221.3	62.0	0.0793	200.6	68.0	184.0	40.5	0.4828

[a]Significant difference between male Soldiers and Triathletes
[b]Significant difference between female Soldiers and Triathletes

pacity testing should be incorporated both in the methodology for examining *Predictors of Injury and Optimal Performance* and in the *Design and Validation of Interventions.* The laboratory testing revealed a number of significant differences across all testing categories (Range of Motion and Flexibility; Strength; Balance; Physiology; and Biomechanical variables) between the Soldiers of the 101st and the triathlete group used as comparison.

Injury Surveillance

The injury epidemiology collected on Soldiers of the 101st describes the magnitude, nature, scope, and impact of the injury problem and was the first step of our model, *Injury Surveillance*. Data was collected based on self-report surveys in which Soldiers were asked to describe the anatomical location and tissues involved in the injury; whether the injury was acute or chronic; where the injury occurred and during what activity; and what was the mechanism of injury. The results of the current study indicate the need for injury prevention measures to target common shoulder, knee, ankle, and back injuries that occur during physical and tactical training as well as sports and recreational activities. Our injury surveillance is consistent with previous, older studies that demonstrated the need for strategies and interventions to reduce unintentional musculoskeletal injury. Despite this historical evidence and efforts to mitigate unintentional musculoskeletal injury a significant need persists based on the results of the current study. All of the injuries reported in the current study are not preventable, but there are many instances where targeted intervention can successfully reduce injury (see Part II). The prevention of unintentional musculoskeletal injury also has an economic impact as each injury prevented results in a cost of care savings. Depending on the injury and the number of injuries prevented, the cost savings can be substantial and outweighs the cost associated with the prevention measures.[31]

Similar to previous studies, the results of this injury surveillance show that unintentional musculoskeletal injuries are very common. A total of 99 injuries were reported within the group of 241 Soldiers who participated in the injury sur-

	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Hip Flexion at Initial Contact (Degrees)	19.4	7.3	22.7	8.6	0.0943	23.6	6.7	19.5	6.6	0.0958
Left Hip Flexion at Initial Contact (Degrees)	20.7	7.5	24.1	8.2	0.0916	23.6	7.2	19.7	6.6	0.1358
Right Hip Abduction at Initial Contact (Degrees)	-3.7	3.4	-2.1	4.0	0.0816	-2.7	4.0	-2.9	2.5	0.8857
Left Hip Abduction at Initial Contact (Degrees)	-3.8	3.3	-2.8	3.9	0.2614	-3.2	3.9	-2.5	2.2	0.6042
Right Knee Flexion at Initial Contct (Degrees)	17.9	6.1	20.3	8.6	0.1515	20.1	6.4	20.3	5.0	0.9296
Left Knee Flexion at Initial Contct (Degrees)	19.7	6.3	21.4	7.5	0.3174	20.9	5.8	21.7	4.4	0.6959
Right Knee Valgus/Varus at Initial Contact (Degrees)[b]	2.8	5.0	3.4	4.9	0.6522	-0.5	4.4	-4.0	3.8	0.0292
Left Knee Valgus/Varus at Initial Contact (Degrees)	2.8	5.2	1.9	4.5	0.5133	-1.4	4.2	-2.2	2.5	0.5834
Right Knee Maximum Flexion (Degrees)	86.7	18.9	82.9	16.9	0.4483	90.5	14.0	83.7	13.2	0.1817
Left Knee Maximum Flexion (Degrees)	87.6	18.6	83.2	15.9	0.3715	89.8	13.4	87.2	12.7	0.5915
Right Peak Vertical Ground Reaction Force (% BW)	365.3	98.4	332.5	112.9	0.2158	359.2	92.3	309.1	65.7	0.1258
Left Peak Vertical Ground Reaction Force (% BW)	336.1	98.6	312.3	117.8	0.3711	337.0	85.8	297.4	84.9	0.2070

[a]Significant difference between male Soldiers and Triathletes
[b]Significant difference between female Soldiers and Triathletes

veillance survey which represents 410 injuries per 1000 person-years. In a recent study, Hauret et al.[32] used military medical surveillance data to identify injury-related musculoskeletal conditions among non-deployed, active duty service members in the year 2006, and reported the rate of injuries to be 628 injuries per 1000 person-years, which is slightly more than the self-reported rate in our study subjects. There are important methodological differences between the current study and Hauret et al. It is likely that their method of counting could have led to injuries being counted twice if the servicemember sought medical attention more than once, with a gap of more than 60 days between encounters, as is likely to happen with chronic musculoskeletal conditions. The lower rate of injuries in our study may also be because the injuries in our study were self-reported, and some Soldiers may not have reported all injuries. Interestingly, in the case of the majority of injuries, our study subjects were engaged in training or recreational activity/sports at the time of injuries. Combat was responsible for a very small proportion of the injuries. This is similar to findings from previous studies[11, 33] as more casualties have been caused among U.S. troops by non-combat injuries and disease than by combat.[34] Injuries outside of theater can limit the ability to prepare and train for deployment while injuries within theater can reduce the capacity of the individual to participate in tactical missions.

In our study, sprains and strains made up 38.4% (38/99) of all injuries; of these sprains and strains 60.5% (23/38) affected the lower extremity. According to a review of medical and personnel data for non-deployed active duty personnel for 2000–2006 by Jones et al.,[35] sprains and strains were responsible for 48.8% of injury ambulatory visits. Of the total sprains and strains, 49.8% affected the lower extremity. Even though Jones et al. counted injury ambulatory visits and our study counted injuries, the finding from these two studies highlight the relative importance of sprains and strains of the lower extremity. The high numbers of military personnel who seek outpatient care for sprains and strains highlights the need for greater attention to the prevention of these and other common unintentional musculoskeletal injuries.

Even though unintentional musculoskeletal injuries are not life-threatening, they result in pain, morbidity, loss of duty time,[11,12] increased medical costs,[12] disability,[10] medical evacuation from theater,[36] and attrition from the military.[5] All of these previous scenarios can reduce the capability and capacity of the Soldier to train and prepare for deployment and/or tactical missions while in theater. It has been estimated that the medical discharge of one active duty U.S. military member in his or her twenties costs the government approximately $250,000 in lifetime disability costs, excluding health care costs.[37,38] In the year 2005, Cohen et al., estimated that the financial cost of medically boarding one Special Operations or some other highly trained Soldier and retraining a replacement can be more than U.S. $1,000,000.[39]

Epidemiology studies often rely on self-reported data.[40-42] The advantages of using self-report are time-efficiency, easy availability and cost-effectiveness. Also, self-reported injury history can be expected to include information about all injuries that have occurred in the past, whether or not medical care was sought, and even if care was sought from a healthcare professional outside the system from which medical records were obtained. This is expected to give a complete picture of the injury history. An important limitation of self-reported injuries is problems with recall, which increase as the time period between injury occurrence and the self-report increases.[43] In our study, difficulties with recall were minimized by including only those injuries that occurred one year prior to the date of survey. Other potential limitations of self-reported injuries are that Soldiers may not report all their injuries due to the culture of stoicism in the military, and the accuracy of self-reported injuries may be influenced by the level of health knowledge of the study subject. Army medical records are currently being examined and compared to self-reported history to determine validity and correspondence between these two sources of injury surveillance data.

Task and Demand Analysis

We modified the traditional approach to injury prevention and performance optimization to address different populations, different environments, and the different needs of the study population by adding *Task and Demand Analysis*. The goal of the *Task and Demand Analysis* is to determine the specific functional needs of the population to be examined. The information gathered in this step drives the specific methodology for examining *Predictors of Injury and Optimal Performance* and is also incorporated into *Design and Validation of Interventions*. These analyses are performed in the field and include qualitative and quantitative study of tasks that the specific population has to perform as part of their daily duties.

The task analysis described was based on exiting a vehicle and includes landing forces that can potentially increase joint loading forces. The vertical component of the landing forces (vertical ground reaction force) can increase joint loading significantly as these forces are transmitted up the lower extremity kinetic chain. The individual Soldier is at potential risk for injury if he or she is unable to efficiently absorb and distribute these forces.[44] The horizontal component which is typically measured as anterior-posterior ground reaction forces in a laboratory setting is a significant predictor of proximal anterior tibia shear force,[29] the most direct loading mechanism of the anterior cruciate ligament.[45, 46] Combined, these different forces place significant demands on the individual Soldier that require sufficient strength, efficient movement patterns, and appropriate timing/activation of the muscular restraints necessary for dynamic joint stability. These demands can be compounded when carrying additional load[30] and landing on unlevel terrain. The task analysis presented in the current manuscript was the driving factor for including a simulated landing (vertical drop landing) in the laboratory testing (see *Predictors of Injury and Optimal Performance*). The investigation of this task in a controlled laboratory environment provides insight into the kinematic and kinetic characteristics necessary for maintenance of dynamic joint stability.

During the O-Course training, physiological responses were calculated for each individual run, total run time, as well as the entire 24 minute training activity. The Solider studied expended 196 kcals (~10 kcals per minute) during the entire O-course training session which is equivalent to 10 METs, requiring energy similar to activities such as walking and carrying a 50-74 pound load upstairs, swimming freestyle vigorously or running six miles per hour.[47] The O-Course is a relatively high intensity activity, where approximately 67 % of the time was spent exercising greater than or equal to 60% of VO_{2max} (moderate to high intensity), of that 32% of time was spent at power outputs greater than or equal to the anaerobic threshold. The first run was completed at a high intensity (at or above the lactate threshold) for ~62% of the run; however, during the second run the ability to achieve and sustain a high intensity power output dropped to approximately ~11% and run time increased by 2 minutes and 20 seconds. Further, the subjects heart rate did not return to baseline between runs and both average and peak heart rate were higher during the second run. The performance decrement observed in the second run may be the result of inadequate adaptations of the aerobic energy system to buffer and clear lactate and to facilitate recovery during multiple bouts of high intensity exercise. Activities performed above the lactate threshold rely predominantly on anaerobic metabolism, including the phosphagen and glycolysis energy systems. These energy pathways utilized phosphocreatine and glucose (carbohydrate) exclusively to resupply ATP for muscle contraction. Training at intensities below the lactate threshold rely predominantly on aerobic metabolism and thus the remainder of time during the O-course the Soldier relied on a combination of carbohydrate and fat to supply to fuel muscle contraction. Thus, it appears that both anaerobic and aerobic energy systems are important for meeting the demands of the O-Course training. Knowing the metabolic and physiologic demands enables physical training programs and feeding strategies to be developed that adapt and fuel the muscles to optimally perform and expedite recovery between bouts of strenuous exercise. Additionally, all of the observations and measurements made across all of the task and demand analyses performed facilitated the design of both the methodology and protocols utilized in *Predictors of Injury and Optimal Performance* and the training strategies to be employed in the *Design and Validation of Intervention.* There are some limitations to this approach. First, the tasks analyzed must be specific to the population studied and specific to the tasks performed by the individuals within that population, otherwise these analyses may not applicable and their usefulness in protocol and intervention design would be diminished. Second, these analyses do not take into account the cognitive aspects of the tasks analyzed. Unfortunately, the analyses of the cognitive aspects of functional tasks do not provide the objective measures necessary to drive protocol and intervention development.

Predictors of Injury and Optimal Performance

The goal of the laboratory testing of Soldiers is to identify *Predictors of Injury and Optimal Performance*. The specific laboratory tests included in this study were based on the task and demand analyses performed on Soldiers of the 101st. The current study is a descriptive comparison of Soldiers of the 101st compared to triathletes. The data presented is part of a larger ongoing study in which each of the Soldiers are enrolled in a prospective study during which injuries will be tracked in order to match the neuromuscular, biomechanical, physiological, and nutritional characteristics to risk of injury. The comparisons performed in the current manuscript between Soldiers of the 101st and triathletes demonstrated numerous, significant differences across many of the testing variables. Although these comparisons are descriptive and retrospective in nature, they do reveal the need for a revision of current training regimes in order to prevent injury and optimize performance. Examples can be found for both injury prevention and performance optimization for both genders and across all of the testing areas (range of motion, flexibility, strength, balance, physiology, and biomechanics).

Range of motion (ROM) and flexibility has traditionally been the target of physical training programs in order to decrease the risk of injury. The comparisons between groups in the current study revealed significant differences across many of the variables. For some of the variables, the Soldiers of the 101st (both genders) demonstrated better ROM/flexibility than the triathletes, but there were a few instances where the Soldiers demonstrated decreased flexibility. For example, both genders within the 101st group demonstrated significantly higher (represented by lower scores) posterior shoulder tightness than the triathletes. Tightness of the posterior capsule of the shoulder has been implicated as a contributor to abnormal kinematics of the scapula and shoulder impingement.[48, 49] Correction of this tightness utilizing stretching and mobilization has been demonstrated to be capable of resolving symptoms observed in individuals diagnosed with internal shoulder impingement.[50]

Measurement of strength characteristics provides insight into both injury prevention and performance optimization. Our previous research has demonstrated that athletes who perform at elite levels typically have developed greater strength than those athletes who perform at recreational levels and that strength is significantly correlated to performance.[23] Additionally, our research examining female athletes who are at greater risk for ACL injury demonstrate decreased quadriceps and hamstrings strength compared to male athletes.[51] Other individuals have demonstrated that inadequate agonist/antagonist strength ratios (quadriceps/hamstrings) can predict both ligamentous injury[52] and muscular injury such as hamstring strains.[53-55] In the current study, the 101st Soldiers (both males and females) had lower knee flexor, knee extensor, and flexion/extension strength ratios compared to the triathletes, all of which may indicate a propensity for injury. The analysis utilized in the current study was based on a comparison of means which may not be as important as a subject by subject examination of data. Within each variable

data set there are individuals who had very low strength values compared to both the mean of the triathletes and also the mean of the 101st Soldiers. For instance, 17% of the male Soldiers and 19% of the female Soldiers had hamstring strength values that were lower than one standard deviation below the respective means of the male and female triathletes. These individuals will particularly benefit from an intervention program as they theoretically may have greater potential for improvement.

Overall, there were no significant differences in balance between Soldiers of the 101st and the triathletes. Balance testing has been previously utilized to examine risk of injury and or potential risk of injury.[56-62] Although the mean of the Soldiers tested is not significantly different than those triathletes tested, there remains a subgroup of Soldiers who may be at greater risk for injury. A systematic review of studies examining the relationship between ankle injuries and balance demonstrated that poor balance is associated with lateral ankle sprains.[63] Those individuals with the lowest balance scores were more likely to suffer an ankle injury than those with the best scores. Although methodological differences exist between the previous studies and the current manuscript, with prospective data it will be possible to set a criterion below which an individual would be at greater risk for injury. It is more than likely that with such a large group of individual tested in the current study, there are individuals who will suffer ankle injuries and likely their scores on the balance test would reveal this potential risk. For example, McGuine et al., examined, prospectively, 210 individuals balance and demonstrated that the 23 individuals who suffered an ankle sprain had balance scores that were 15% worse than the mean.[64] Willems et al., performed a similar study that demonstrated that the 44 individuals (out of 241) who suffered an ankle sprain had balance scores that were 24% worse than the mean.[65] Within the current study's Soldier group, 23% (61/266) of the males and 20% (10/51) of the females were worse than 15% of the mean and 19% (51/266) of the males and 14% (7/51) of the females who were worse than 25% of the mean (eyes open balance test).

The majority of physiological comparisons revealed that the triathletes had greater aerobic and anaerobic capacity as well as less body fat than the 101st Soldiers. Without appropriate context it is difficult to determine the clinical relevance of these results for the 101st Soldiers, but overall, the results do reveal a need to revise current training activities in order to optimize these physiological systems and characteristics to meet the demands placed on the individual Soldier. Our *Task and Demand Analysis* step provides the bridge between the physiological and physical demands of 101st Soldiers and the physical training necessary to meet those demands. For example, the data presented for the *Task and Demand Analysis* section in the current manuscript demonstrated the need for anaerobic training based on the Soldier's reliance on the anaerobic energy system as a significant contributor to the muscle fuel requirements during the O-Course training.

Although there were no significant differences in the biomechanical characteristics between the 101st Soldiers and the triathletes, a more careful examination of the data indicates that the Soldiers may display characteristics that could predispose them to injury. Prospective studies have demonstrated that landing with high vertical ground reaction forces and with a large knee valgus angle predict knee ligament injury.[58] Additionally, although not demonstrated prospectively, landing with a low flexion angle can increase anterior cruciate ligament strain significantly.[46, 67-70] Both male and female Soldiers had a subset of individuals who landed with a knee valgus angle greater than five degrees, which has been identified as a predictor of anterior cruciate ligament (ACL) injury.[66] Additionally, the mean values for peak vertical ground reaction force in the Soldiers (both genders) was approximately 365% body weight which is much higher than those values observed in a group of athletes who suffered ACL ruptures (210% body weight).[44] Finally, the knee flexion angle at landing in the male Soldiers was less than 20 degrees which can increase strain considerably in the ACL compared to greater knee flexion angles.[46, 67-70] The comparisons above are limited based on slightly different protocols between the current study and the referenced studies. They only indicate the potential for injury and not necessarily risk for injury. Regardless, it demonstrates that there are Soldiers who demonstrate potentially injurious biomechanical characteristics during tasks when knee injuries occur that indicate the need for training activities that target modification of motion patterns and strength. This potential for injury may be exacerbated while wearing body armor as our previous study has demonstrated that the addition of body armor significantly increases ground reaction forces and landing kinematics.[30]

In summary the laboratory data collected including the comparisons to the *Task and Demand Analysis* data and the comparisons to triathletes provides the part of the framework for the design of the intervention. Triathletes were used as a comparison for the current manuscript, but other groups of athletes (hockey, football, soccer, and basketball) have also been tested in order to benchmark the 101st Soldiers to individuals who have optimized different physical characteristics. For example, the group of triathletes in the current study have all competed in accredited full-length triathlons and have qualified (age group) for world championship events. Presumably, this group of athletes has optimized aerobic conditioning as well as anaerobic capacity. Depending on the target study group, Soldiers of the 101st in the current manuscript, this data can serve as a benchmark for specificity of training. Other groups of athletes can serve a similar purpose related to other characteristics. Although the laboratory tests utilized in the current study may not be functional tasks that Soldiers perform, we contend that the characteristics (strength, aerobic capacity, anaerobic capacity, balance, and flexibility) measured describe the underlying components/processes necessary for the performance of functional tasks of the Soldier. Therefore, improvements in these characteristics should provide the foundation for improvements in functional tasks of the Soldier. The injury data (currently being tracked and part of the ongoing investigation) combined with the prospective testing of

Soldiers will also dictate specific activities for the intervention. One potential limitation for the comparison group in the current study is the age of the triathletes. The mean age of the triathletes was approximately seven years older than the Soldiers mean age. This difference in age may confound the comparisons and subsequent results. Age was not controlled in the current manuscript due to the low subject numbers in the triathlete group. Other potential confounding were also not controlled (nutrition, tobacco use, sleep (quality and amount), and supplementation and may warrant further investigation

Conclusions

Unintentional musculoskeletal injuries are preventable with scientifically driven and culturally-specific interventions. Our approach is based on a conventional public health model of injury prevention. The model of research described in the current paper and Part II of these companion papers describes a specific application to the 101st Airborne Division (Air Assault). This model, by design, can be implemented in any population of military personnel, including Special Operations Forces. It may be particularly suited to application in Special Operations Forces due to the elite athlete benchmarking and the ability to individualize to the specific needs of each Operator. Through *Injury Surveillance*, we have demonstrated that Soldiers of the 101st continue to suffer common and preventable injuries during physical training, tactical training, sports, and recreational activities. Our *Task and Demand Analysis*, which is the hallmark of our comprehensive approach, drives the specificity of the testing methodology and contributes to the *Design and Validation of Interventions*. The task and demand analyses performed for this study demonstrated the need to test multiple flexibility, range of motion, strength, physiological, and biomechanical variables in order to determine risk factors for injury. The data analysis identified a number of characteristics of 101st Soldiers that should be targeted with specific physical training. Part II of these companion papers outlines the *Design and Validation of Interventions* for the 101st, the process of *Program Integration and Implementation*, and the methods to *Monitor and Determine the Effectiveness of the Program*.

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Minimal Additional Weight of Combat Equipment Alters Air Assault Soldiers' Landing Biomechanics

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ABSTRACT   The additional weight of combat and protective equipment carried by soldiers on the battlefield and insufficient adaptations to this weight may increase the risk of musculoskeletal injury. The objective of this study was to determine the effects of the additional weight of equipment on knee kinematics and vertical ground reaction forces (VGRF) during two-legged drop landings. We tested kinematics and VGRF of 70 air assault soldiers performing drop landings with and without wearing the equipment. Maximum knee flexion angles, maximum vertical ground reaction forces, and the time from initial contact to these maximum values all increased with the additional weight of equipment. Proper landing technique, additional weight (perhaps in the form of combat and protective equipment), and eccentric strengthening of the hips and knees should be integrated into soldiers' training to induce musculoskeletal and biomechanical adaptations to reduce the risk of musculoskeletal injury during two-legged drop landing maneuvers.

INTRODUCTION

Musculoskeletal injury is a persistent and major health concern for individuals who are responsible for the medical care of military personnel. According to the Armed Forces Epidemiological Board (AFEB), injuries "impose a greater ongoing negative impact on the health and the readiness of U.S. armed forces than any other category of medical complaint during peacetime and combat."[1] More casualties have been caused among U.S. troops by noncombat injuries and disease than by combat.[2] Data presented to the AFEB's Injury Control Work Group by scientists from Navy and Army research organizations, and published military and civilian epidemiologic studies has revealed that the most common types of injuries seen in military populations are unintentional musculoskeletal overuse injuries.[3] A review of the medical treatment records in a group of 298 male infantry soldiers showed that musculoskeletal injuries were very common; musculoskeletal pain was the most common diagnosis followed by strains. Also, a higher cumulative incidence of soldiers with musculoskeletal injuries was associated with reduced physical fitness (2-mile run and sit-ups).[4] A study of data in an Army database of all hospital admissions (caused by an external injury) for active duty personnel showed that during a 6-year period, 11% (13,861) of the patients had injuries sustained during sports or physical training. Of these, musculoskeletal injuries were very common (fractures, 33%; sprains/strains, 29%; and dislocations, 15%). Sports and Army physical training inju-

ries accounted for a significant amount of lost duty time.[5] An analysis of the Navy Physical Evaluation Board data showed that the most common diagnostic categories of cases were musculoskeletal disorders (43%) and injuries and poisonings (15%).[6] Recently, a survey by Sanders et al.[7] among military personnel involved in Operations Iraqi Freedom and Enduring Freedom revealed that 34.7% of soldiers reported noncombat injuries.

Musculoskeletal conditions and injuries are the leading causes of hospitalization in the U.S. Army, accounting for 31% of all hospitalizations in 1992.[8] Orthopedic and musculoskeletal issues accounted for 53% of all U.S. Army injury cases that were reviewed by the disability evaluation process of the physical evaluation board in 1994.[9] Similarly, 58% of such cases in 2005 in the U.S. Navy were caused by musculoskeletal conditions and injuries.[6] The high rate of overuse injuries adversely affects military training, resulting in lost days and increased medical costs.[10] The annual cost of injury-related disability in the military had exceeded $750 million in the mid-1990s,[1,9] and the annual expenditure of the U.S. Department of Defense to treat musculoskeletal injuries had been $600–750 million before 2001.[11] Such injuries will have long-term consequences even after individuals have left active duty. For example, among the veterans returning from Iraq and Afghanistan who have sought Veterans Administration health care between 2002 and 2006, 42% were related to musculoskeletal issues such as joint and back disorders.[12]

The knee is one of the most common sites of musculoskeletal injury in the military, accounting for 10–34% of all injuries among different military groups from Army infantry to naval special warfare trainees.[3] The mechanism responsible for knee injuries in the military has not been clearly outlined, but they are hypothesized to be similar to the mechanism responsible for knee injuries in athletes. Most traumatic noncontact knee injuries occur during demanding athletic tasks that include sudden deceleration, landing, and pivoting

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maneuvers,[13] which are all prevalent in military training, tactical operations, and sports activities. Among these tasks, landing from a raised platform may be one of the most critical and the most common. Landing is involved widely in infantry soldiers' training and operations, such as jumping off the back of a vehicle, traversing a ditch, and landing after a climb over a wall or other obstacle.

These landings typically induce dangerously high ground reaction forces, which will be transferred through the knees. Biomechanical and epidemiological research has linked several dangerous kinematic and kinetic characteristics during landing to a greater risk of noncontact anterior cruciate ligament (ACL) and secondary injuries in athletes.[14,15] Our own research has demonstrated that groups at risk for knee injury perform landing and cutting maneuvers with dangerous landing positions, which includes greater ground reaction forces, altered electromyographic activity, and increased joint loading.[16–19] Because of similar injury mechanisms in the military, the same models employed to study biomechanics in athletes are appropriate for use in military populations.

Although soldiers perform very different tasks than typical athletes, soldiers must be able to perform and react similarly and can be considered tactical athletes. While athletes can sometimes modify equipment (lighter shoulder pads in football for instance), soldiers do not have the convenience of improving their agility in the field by using lighter equipment. Instead, soldiers must wear the required heavy and uniformed protective equipment and must also carry weapons, ammunitions, communication devices, and other equipment for combat. The weight a soldier carries while marching has increased throughout the past century.[20] Such additional weight can alter soldiers' normal body movement patterns, increase joint stress, and potentially increase their risk of suffering musculoskeletal injuries. For example, Army officials have reported that the 60–70 kilograms of weight (approximately 65% to 75% of the soldier's body weight [BW]) that U.S. soldiers routinely carry in the mountains of Afghanistan has increased the number of soldiers who have been categorized as "nondeployable" because of musculoskeletal injuries.[21] Previous research studies demonstrated that carrying a military rucksack (approximately 15%–30% of the soldier's BW) can initiate compensatory kinetic response at the knees,[22] elevate the forces applied on the upper and lower back,[23] and increase the thoracic and lumbar spine curvature.[24] The additional weight may also alter landing kinematics and ground reaction forces. Kulas et al.[25] studied the effect of a vest of 10% BW on recreationally active civilian participants performing two-legged drop landing from a 45-cm-height platform. They reported increased angular impulse and energy absorption but no significant change in maximum knee flexion angles, whereas ground reaction forces and knee valgus angles were not mentioned.[25]

The biomechanical response to additional weight has not been extensively studied in a military population. Therefore, the main purpose of this study was to investigate the effects of additional weight on soldiers' kinematics and kinetics and their potential implication on lower extremity musculoskeletal injury using similar biomechanical models we have previously employed in athletes.[16–19] Although the effects of additional weight should be observed throughout the lower extremity, we chose the knee joint as the main focus of this study. We used standard military body armor, a helmet, and a rifle to represent the minimal additional weight a soldier would carry in a combat setting. As a part of our ongoing 101st Airborne (Air Assault) Injury Prevention and Performance Optimization Program, soldiers from the 101st Airborne Division (Air Assault) participated in this study. We hypothesized that wearing body armor, a helmet, and carrying a rifle would result in greater knee flexion and knee valgus angles at initial foot contact, greater maximum knee flexion angle, prolonged time from initial foot contact to maximum knee flexion, greater maximum vertical ground reaction forces (VGRF), and a prolonged time from initial foot contact to maximum VGRF, compared to not wearing the additional weight. This study is among a limited number of investigations examining the effect of additional weight on biomechanics of drop landing and is the only one recruiting participants strictly from a military population. We expect the results of this study will provide evidence-based insight to modify soldiers' training, accounting for the necessary loads carried during combat, to reduce the risk of injury.

Methods Participants

Seventy 101st Airborne (Air Assault) soldiers volunteered to participate in this study (age, 28.8 ± 7.1 yr; height, 1.78 ± 0.07 m; weight, 84.1 ± 12.8 kg). To be included, potential participants must have been 18- to 45-year-old males from the 101st, with no history of concussion or mild head injury in the previous year, no upper extremity, lower extremity, or back musculoskeletal pathology in the past 3 months that could affect the ability to perform the required tests, and no history of neurologic or balance disorders. All participants were cleared for active duty without any recent prescribed duty restrictions. Participants provided informed consent before participation. The current study was approved by the university's institutional review board (0506094), Eisenhower Army Medical Center (DDEAMC 07-16), Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office (HRPO A-14020). All tests were conducted at our Human Performance Research Laboratory, Fort Campbell, KY, a remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

Instrumentation

Six high-speed cameras (Vicon, Centennial, CO) operating at 200 Hz were used to capture the participants' kinematic data. Vertical ground reaction forces were measured using two Kistler force plates (Kistler, Amherst, NY) at a frequency of 1,200 Hz. The soldiers used their own personalized intercep-

tor body armor (IBA) (Point Blank Body Armor, Pompano Beach, FL) and advanced combat helmets (Gentex, Simpson, PA) for the test. An assault rifle replica (M4 carbine model) was provided by the researchers. The total weight of the interceptor body armor, helmet, and rifle replica was 15.0 ± 3.7 kg, or 18.0 ± 4.3% compared to each participant's BW. The authors recognize the actual weight carried by the soldiers will vary considerably depending on their work demands and could not control for potential differences between soldiers. The weight of the IBA, helmet, and rifle, however, represented the minimal additional required weight to be carried by the soldiers as part of tactical operations excluding the combat uniform and boots not worn as part of this study.

Procedures

Sixteen reflective markers were placed bilaterally on the participants' anterior superior iliac spines (ASIS), posterior superior iliac spines (PSIS), lateral thigh, lateral femoral epicondyle, lateral shank, lateral malleoli, posterior calcanei, and second metatarsal head (dorsal surface), according to Vicon's Plug-in Gait model (Vicon). The lateral thigh markers (midfemur) were placed in line between participants' greater trochanter (as palpated) and the lateral femoral epicondyle marker, and the lateral shank markers were placed in line between the lateral femoral epicondyle marker and lateral malleolus markers.

A static trial was captured for each participant in the anatomical position and served as the baseline for joint angle calculations. The participants were asked to perform two-legged drop landings from a platform of 50 cm high under two conditions: with and without wearing the IBA, helmet, and rifle; henceforth referred to as the IBA condition (Fig. 1) and non-IBA condition (Fig. 2), respectively. Participants were instructed to stand near the edge of the platform and drop off when the researchers gave the command. The participants were to land on both feet on the two force plates and remain standing for 2 seconds after regaining their balance. The task was described and demonstrated by the researcher. For each condition, the participants were given at least three practice trials. All trials for both conditions were performed on the same day with approximately 30–60 seconds in between trials within each condition and approximately 5 minutes between the two conditions. Trials during which the participants did not drop off the platform properly, failed to regain balance, touched the ground off the force plates, or did not land on the force plates were rejected.

Data Reduction

The 3D coordinates of the video-captured reflective markers were reconstructed and synchronized with the VGRF data using Vicon Nexus software (Vicon Motion Systems,

FIGURE 1. Two-legged drop landing task, IBA condition.
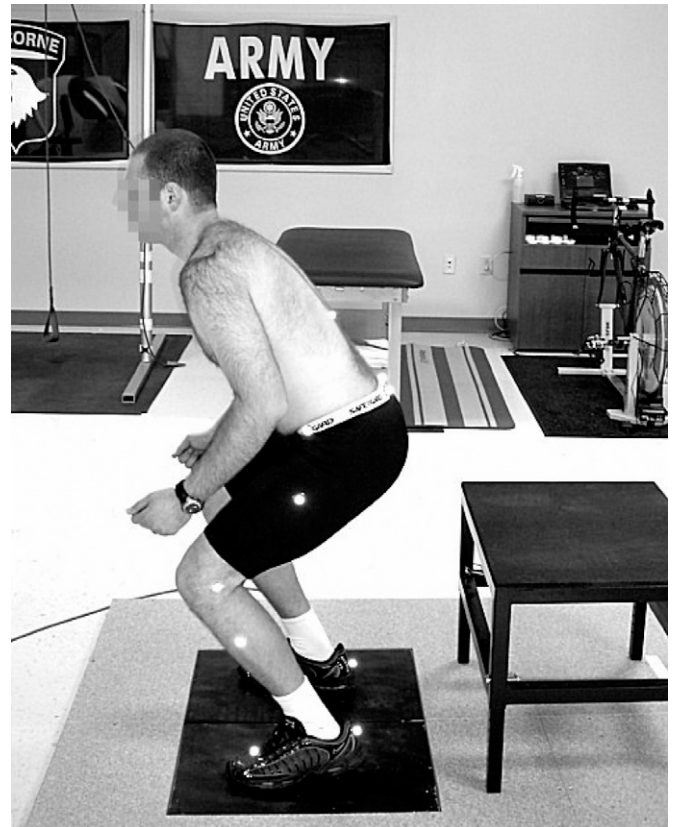

FIGURE 2. Two-legged drop landing task, non-IBA condition.

Centennial, CO). We used a general cross-validation Woltring filter to smooth the reconstructed 3D coordinates.[26] The Vicon Plug-in Gait model uses ASIS and PSIS markers to estimate the position of hip joint centers. However, to account for coverage of the ASIS markers by the IBA, we placed these markers on the IBA itself. Unfortunately, this invalidated the 3D joint angle calculations as they no longer reflected the anatomical landmarks on which they were intended. Therefore we decided to use 2D angles defined only by those markers on the legs, which were not affected by the ASIS markers.

The filtered *x*, *y*, and *z* coordinates and force plate data were processed with a custom Matlab (The MathWorks, Natick, MA) program to calculate joint angles and identify critical events. The knee flexion angle was defined as 180° minus the inner angle formed by lateral thigh, lateral knee, and lateral malleolus projected on the sagittal plane. The knee valgus angle was defined as 180° minus the inner angle formed by the three markers projected on the frontal plane. The joint angles during the dynamic tasks were corrected by the baseline angles from the static trial. Initial contact was defined as the point at which the vertical ground reaction forces exceeded 5% of the participant's body mass. Variables assessed in the current study included knee flexion and knee valgus at initial foot contact, maximum knee flexion, time to maximum knee flexion, maximum VGRF, and time to maximum VGRF. Three trials for each participant were averaged for statistical comparisons.

Statistical Analysis

Dependent *t*-tests were used to examine the differences of selected variables with (IBA) and without (non-IBA) wearing IBA. Each participant would serve as his own control. Statistical analyses were performed using SPSS software (SPSS, Chicago, IL). The α level was set at <0.05.

RESULTS

The results are presented in Table I. The participants demonstrated no statistical difference between the IBA and non-IBA conditions for knee flexion or knee valgus angles at initial contact. Under the IBA condition, the participants had significantly greater maximum knee flexion and greater maximum

VGRF; the time from initial contact to these peak values were also significantly longer.

DISCUSSION

Equipment for personal protection and combat purposes places additional weight on the soldiers' bodies, which might alter their kinematics and kinetics and therefore increase the risk of musculoskeletal injuries. The purpose of this study was to investigate the biomechanical effects of additional weight on air assault soldiers performing landing tasks and the potential implication of the alterations on lower extremity musculoskeletal injuries, using the biomechanics model we previously developed.[16–19] This study focused specifically on the VGRF and knee kinematics during landing, which is a task that air assault soldiers frequently perform during combat activities, such as jumping out of a helicopter or a truck, and traversing uneven terrain or obstacles. On the basis of the 70 soldiers tested, we found greater maximum knee flexion, greater maximum VGRF, and prolonged time from initial contact to these two peak values with additional weight. We believe that specific strength training, proper landing skills, and properly increased exposure to weight carrying during physical training should be addressed to induce musculoskeletal adaptations that will likely reduce the risk of knee injuries in air assault soldiers.

The effects of additional weight carried by soldiers on knee kinematics and VGRF have several implications on training and injury prevention. First, the additional weight requires considerable lower extremity strength to land safely, especially at the knee, as the quadriceps must eccentrically contract to absorb and dissipate landing forces. Momentum is the product of the mass and the velocity of an object. Therefore, the kinetic influence of additional weight on soldiers' bodies and potentially landing kinematics is similar to landing without additional weight from a greater height or, equivalently, with additional weight at greater velocity. Maximum knee flexion angles,[27] as well as the range of knee flexion,[27,28] increases with drop landings from a raised platform height. A simulated parachute landing study demonstrated greater maximum knee flexion, greater range of knee flexion, and longer time to maximum knee flexion when participants dropped from a higher

TABLE I. Comparisons of Knee Joint Angles, Vertical Ground Reaction Forces, and Timings Between Non-IBA and IBA Conditions

	Right Leg			Left Leg		
	Condition			Condition		
	Non-IBA	IBA	*p* value	Non-IBA	IBA	*p* value
Knee Flexion Angle at Initial Contact (°)	10.5 ± 5.6	10.4 ± 5.5	0.905	12.5 ± 6.2	11.8 ± 6.5	0.107
Knee Valgus/Varus Angle at Initial Contact (°) (Positive = Valgus, Negative = Varus)	0.0 ± 10.1	−1.0 ± 11.8	0.466	−2.9 ± 13.8	−3.7 ± 14.8	0.566
Maximum Knee Flexion Angle (°)	76.2 ± 17.6	82.2 ± 14.4	<0.001	77.6 ± 18.8	84.4 ± 16.4	<0.001
Time to Maximum Knee Flexion Angle (ms)	239 ± 88	298 ± 73	<0.001	240 ± 102	292 ± 76	<0.001
Maximum Vertical Ground Reaction Force (Percent Body Weight)	371.2 ± 100.7	398.1 ± 94.3	0.002	330.5 ± 96.7	374.6 ± 88.2	<0.001
Time to Maximum Vertical Ground Reaction Force (ms)	37 ± 11	42 ± 9	<0.001	36 ± 12	40 ± 10	0.004

Statistical significance set at *p* < 0.05.

position.[29] During knee flexion, the knee extensors eccentrically contract to decelerate the body, and dissipate the impact, and absorb the energy transferred up from the ground.[28,30] As expected, our participants demonstrated increased maximum knee flexion and a longer time to reach maximum flexion with IBA; it naturally takes more knee angular displacement and time to stop the downward movement of the body with increased momentum. When such demand increases, a greater portion of the energy absorption shifts to the knee and hip extensors from the ankle muscles,[28,30,31] which have limited energy-dissipation capacity. The eccentric strength of knee extensors are considered a potential factor affecting maximum knee flexion during landing.[16] Although our participants demonstrated an appropriate adaptation of flexing the knees more, the additional weight added in the current study was only minimal and may not be reflective of actual carrying loads. As carry loads increase during tactical operations, the demand on muscular strength, especially eccentric strength at the knees and hips, would increase significantly to perform safe landings.

Second, proper landing techniques should be emphasized to address the increased VGRF and accompanied risk of injury. The vertical ground reaction force induces an external knee flexion torque. To counterbalance and control the knee flexion torque, there exists an internal knee extension torque (quadriceps activation), which simultaneously increases the ACL strain by producing an anterior shear force on the proximal tibia.[32] Our previous research has demonstrated that the greater the internal knee extension torque, the greater the proximal tibia anterior shear force.[19] Activation of the quadriceps, which increases anterior shear force by way of the patella tendon,[32] is also preactivated before initial contact.[29,33–35] Depending on the knee alignment at the instant of landing, the VGRF may increase the knee valgus torque, which can further increase ACL strain in the presence of anterior shear force at the knee.[36,37] Valgus alignment of the knee at landing has been considered a risk factor for noncontact ACL injury.[15] In addition to landing with greater knee valgus, those individuals at greater risk for injury experience greater proximal tibia anterior shear force during landing even when their vertical and posterior ground reaction forces are not significantly higher than those at less risk for noncontact ACL injury.[18] Although our participants did not show any sign of more dangerous knee alignment in the frontal plane with additional weight, the increased maximum VGRF they experienced has been linked to increased risk of noncontact ACL injuries.[15]

In the current study, an average of 18% of additional weight increased the maximum VGRF by 35% BW on each leg (based on data derived from Table I); with the additional weight of weapons, ammunition, and other combat equipment, the maximum VGRF during landing is expected to increase dramatically in tactical operations. In a previous study, the vertical ground reaction forces increased from 256% BW to 474% BW as the height of the dropping platform rose from 32 cm to 103 cm (equivalent to an increased velocity from 2.5 m/s to 4.5 m/s).[28] Our 50-cm platform, equivalent to a 3.1 m/s velocity, yielded a comparable 355% BW maximum VGRF under the non-IBA condition and 391% BW under the IBA condition. A high mobility multipurpose wheeled vehicle (HMMWV), widely used by the U.S. Army, has a deck height of approximately 84 cm, and the height of a window or a wall and the depth of a ditch can be close to a meter or more. Moreover, the maximum VGRF experienced during landing tasks performed in the field could be much greater than the standardized drop landing task performed indoors. A simulated parachute landing yielded 930% BW (9.3 times body weight) and 1,310% BW (13.1 times body weight) of maximum VGRF at vertical velocities of 3.3 and 4.5 m/s, respectively.[29] Such high VGRF was very close to the greatest value ever documented, in a single-leg double back somersault landing (1,440% BW).[38] The exact reason for such a large increase in maximum VGRF between tasks is difficult to determine; however, performing such a task is more dynamic, and has much higher uncertainty and unpredictability than a well-controlled standardized task. During tactical operations soldiers will quickly react to the environment and operation conditions and may not have time to prepare for the landing. In such context, soldiers may not be able to use their full capacity to reduce the impact. Thus, we would expect an even higher maximum VGRF that the air assault soldiers would encounter frequently in the battlefield.

One technique to reduce the VGRF is to increase the knee flexion angle at initial contact, and allow greater knee flexion throughout the landing.[28,30] Females, who are more vulnerable to noncontact knee injuries, demonstrate lower knee flexion angles at initial contact during two-legged landing,[14,27] although a limited amount of research has shown no gender differences[39] or increased knee flexion in females.[34] With less knee flexion, less energy can be absorbed, and more energy is transferred to the knees and hips from the ankles. We hypothesized that the knee flexion angles at initial contact would be greater under the IBA condition, assuming the additional weight would lead to a more cautious move. However, our participants demonstrated no statistical difference between conditions. We do not have sufficient information to conclude whether soldiers would land with a more extended knee when additional weight is carried on the basis of the current study and research design. Although the effect of additional weight was similar to increased dropping velocity in many ways, we also do not have a clear answer as to how a greater velocity would affect the knee flexion angle at initial contact. Huston et al.[27] found that knee flexion angle increased with increasing velocity during two-legged drop landings. In contrast, a more extended knee with greater velocity was observed in simulated parachute landing, which may explain the concurrent high maximum VGRF observed.[29] Although the task Huston et al.[27] used was more comparable to ours, the results from the simulated parachute landing may be more valuable to our research purposes. We cannot rule out the possibility that soldiers would land with more extended knees performing tactical operations in the field with additional weight.

In this study, we demonstrated the effect of additional weight on knee kinematics and VGRF of soldiers performing a two-legged drop landing task. These effects may increase the risk of lower extremity musculoskeletal injuries during a similar landing task; however, landing is not the only task that the additional weight could affect, and the knee is not the only joint subjected to increased risk of injury under the increased stress because of the additional weight. Military load carriage can also increase the ground reaction forces during walking,[40] alter pelvic and hip angles during standing,[41] and decrease balance and postural stability.[42] Craniovertebral angle and femur range of motion,[43] thoracic and lumbar spinal curvature,[24] forces suffered at the upper and lower back,[23] and trunk muscle activation patterns[41] can all be adversely affected by additional weight. Alterations in physiological performance, such as increased oxygen consumption, heart rate, ventilation, perceived exertion, and decreased knee muscle extension torque output were all evident in a simulated marching test with increased carried weight, suggesting the fatiguing effects of the heightened demands of additional load.[22,44] Our preliminary data from another study has also demonstrated similar effects with additional load (body armor and helmet = 18.6 kg). The addition of the body armor and helmet increased the peak VGRF during gait by 18.7% BW and the time to exhaustion during a VO2 max test decreased by 50% and caloric expenditure increased by 20%. Considering the trend of increasing weight carried by soldiers throughout history,[20] the effects of this weight on soldiers' performance and safety in tactical operations is an ongoing concern for soldiers' effectiveness and safety.

Because additional weight considerably increases the mechanical and physiological demands and potentially contributes to musculoskeletal injuries, integrating additional weight into soldiers' regular physical training seems prudent. Soldiers build their strength through their daily Army physical training and sharpen their combat skills through regular tactical training. However, soldiers frequently wear only fitness clothing and running shoes during physical training. Additional weight may be worn during tactical training, yet a progressive program to induce adaptations has not been implemented. On the other hand, during their deployment, soldiers are equipped with additional weight sometimes significantly more than encountered in previous physical and tactical training. The inconsistent exposure to additional weight during training may not induce the musculoskeletal demands to allow soldiers to build and maintain sufficient strength and develop adequate kinematic adaptations to meet the combat mission tasks. Increased integration of additional weight into physical training that simulates the demand of their tactical operations is therefore encouraged, as it may reduce the risk of injuries and promote soldiers' combat readiness.

We acknowledge this study has several limitations. First, we had to use 2D projection angles instead of 3D joint angles because of marker placement issues. Knee flexion and knee valgus angles can affect each other when the values are large.

However, we only assessed knee valgus angle at initial contact, while knee flexion angles were small. And the knee valgus angle was low throughout the landing task and would have limited effect on the knee flexion angles. Second, the order of the two testing conditions was not randomized. A learning effect could have influenced the measurements during the IBA condition because it always followed the non-IBA condition. In an attempt to address this issue, we provided at least three practice trials for each condition and allowed more practice until participants felt comfortable and prepared. We believe participants could familiarize themselves with the landing tasks through practice, and therefore the order of the two testing conditions would not provide further alteration of performance. We also felt this order of testing was a safer protocol. Third, the current study did not include ankle kinematic calculations. Lephart et al.[16] suspected that ankle kinematics may affect the VGRF of landing tasks. Future studies investigating how the ankles would respond with increasing mechanical demands could provide additional insight of military injury prevention, particularly given the rate of ankle injury.

CONCLUSION

Even the minimum additional weight soldiers carry such as the addition of body armor, helmet, and a rifle, causes altered kinematics and ground reaction forces. These alterations attributed to carrying additional weight may increase the risk of knee and other lower body injuries. Gradually integrating additional weight, such as body armor, into the soldiers' physical training is recommended to promote kinematic adaptations and safer performance during landing tasks.

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Warrior Model for Human Performance and Injury Prevention: Eagle Tactical Athlete Program (ETAP) Part II

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ABSTRACT

Introduction: Physical training for United States military personnel requires a combination of injury prevention and performance optimization to counter unintentional musculoskeletal injuries and maximize warrior capabilities. Determining the most effective activities and tasks to meet these goals requires a systematic, research-based approach that is population specific based on the tasks and demands of the Warrior. **Objective**: The authors have modified the traditional approach to injury prevention to implement a comprehensive injury prevention and performance optimization research program with the 101st Airborne Division (Air Assault) at Fort Campbell, KY. This is second of two companion papers and presents the last three steps of the research model and includes *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program*. **Methods**: An 8-week trial was performed to validate the Eagle Tactical Athlete Program (ETAP) to improve modifiable suboptimal characteristics identified in Part I. The experimental group participated in ETAP under the direction of a ETAP Strength and Conditioning Specialist while the control group performed the current physical training at Fort Campbell under the direction of a Physical Training Leader and as governed by FM 21-20 for the 8-week study period. **Results**: Soldiers performing ETAP demonstrated improvements in several tests for strength, flexibility, performance, physiology, and the APFT compared to current physical training performed at Fort Campbell. **Conclusions**: ETAP was proven valid to improve certain suboptimal characteristics within the 8-week trial as compared to the current training performed at Fort Campbell. ETAP has long-term implications and with expected greater improvements when implemented into a Division pre-deployment cycle of 10-12 months which will result in further systemic adaptations for each variable.

INTRODUCTION

This paper is the second of two companion papers detailing the systematic and data driven injury prevention and performance optimization training program (Eagle Tactical Athlete Program- ETAP) to reduce the risk of unintentional musculoskeletal injuries and improve physical readiness in Soldiers of the 101st Airborne Division (Air Assault). This six step injury prevention and performance model was developed based on the conventional public health approach to injury prevention and control[1-3] and was modified to include *Task and Demand Analysis*. The first three steps of the model were detailed in Warrior Model for Injury Prevention and Human Performance: Eagle Tactical Athlete Program (ETAP) – Part I and included *Injury Surveillance*, *Task and Demand Analysis*, and *Predictors of Injury and Optimal Performance*. The current paper describes the last three steps of the model and includes *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program*.

At the initiation of this research with 101st Airborne Division (Air Assault), the standard physical training guideline used at Fort Campbell was Field Manual (FM) 21-20, published by the Department of the Army.[4] Although this manual covers the fundamental principles of cardiovascular fitness, body composition, muscular endurance, strength, and flexibility, anecdotal reports suggest daily physical training still emphasizes training for performance on the Army Physical Fitness Test (APFT): push-ups, sit-ups, and two-mile run. This assessment encompasses few of the characteristics critical to achieve optimal physical readiness and performance, or reduce injury risk.[5] Unfortunate consequences of

such isolated training increase the risk of certain musculoskeletal injuries.[6]

Several military and civilian based training programs have been developed and/or marketed as training programs specific to U.S. Army Soldiers.[7-9] Common to these programs is the concept of treating the Soldier as a "tactical athlete." Consequently, these physical training programs are similar to strength and conditioning programs developed for athletes at the university and/or professional level, incorporating aerobic and anaerobic components as well as muscular strength, endurance, and agility. While a few programs have been based on predictors of injury and optimal performance,[10] none of the programs were developed based on injury surveillance of military populations in which the program was implemented or the physiologic, musculoskeletal, and biomechanical demands associated with military-specific training and tactical operations. Many of the programs target individual Soldiers rather than units, potentially making it difficult to implement the program on a larger scale.[7-9] Additionally, few studies have designed and validated an intervention program using Soldiers in regular Army combat units, whose training schedule is largely influenced by deployment cycles and their associated preparatory activities. Only a few of these training programs have been evaluated to determine if the risk of injury is reduced while maintaining or improving physical performance, including the APFT.[11] Consistent with the public health approach to injury prevention and control,[1-3] it is imperative to monitor and determine the effectiveness of these training interventions to reduce injury and optimize performance.

The purpose of this paper is to describe the last three steps of the research model- *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program*,. It was hypothesized that performance of ETAP would result in favorable adaptations to laboratory, field, and APFT performance compared to the current training performed at Fort Campbell as governed by FM 21-20.

Design and Validation of Interventions
<u>Methods</u>
Subjects

A sample of 60 male and female Soldiers from the 101st Airborne Division (Air Assault) were recruited from a single Brigade through posted advertisements and information sessions arranged by the investigators. All subjects were cleared for active duty without any injury profile prescribed throughout the study period or within the three months prior to enrollment. Subjects were matched on age, gender, and two-mile run time from their last APFT and then one member of each pair was randomly assigned to either an experimental group- ETAP (N: 30, Age: 24.6 ± 5.2 years, Height: 168.5 ± 24.5cm, Mass: 68.3 ± 3.3kg) or control group- current PT (N: 30, Age: 25.1 ± 5.8 years, Height: 168.5 ± 25.5cm, Mass: 69.1 ± 3.3kg). Human subject protection for the current study was approved by the University of Pittsburgh, Dwight D. Eisenhower Army Medical Center, Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office. All tests were conducted at the Human Performance Research Center, Fort Campbell, KY, a remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

ETAP Overview

ETAP is a cyclic program which allows for modifications to the individual training cycles according to unit schedules and missions. When implemented, each cycle is separated by one to two weeks of tapered activity to ensure proper recovery and to reduce the risk of overtraining. Each cycle is designed to build upon the previous cycle and varies in intensity and duration. ETAP is designed for implementation with little to no equipment and can be easily executed in garrison or while deployed. Overall volume, intensity, rest, and distance varies across the phases: phase I focuses on general adaptation and introduction to the exercises; phase II focuses on gradual increase in volume; phase III focuses on gradual increase in intensity with less volume, and phase IV focuses on taper prior to the post-test, deployment, or cycle reset. The program consisted of five main workout sessions per week over eight weeks, each with a specific fitness component focus (Table 1). Each workout session began with a dynamic warm-up and finished with a cool-down and static stretching. Each session was dedicated to one of the following training objectives: Day-1) speed, agility, and balance; Day-2) muscular strength; Day-3) interval training; Day-4) power development; and Day-5) endurance training. The total workout duration for each daily physical training session was consistent with the guidelines published in FM 21-20 and as instructed at Fort Campbell.

The Day-1 workout session was designed to improve anaerobic power and capacity (which were identified as suboptimal during *Predictors of Injury and Optimal Performance*) and incorporated speed and agility exercises. Interval training with approximately a 1:3 or 1:2 work to rest ratio was incorporated for anaerobic system enhancement. Activities included shuttle runs, sprints, lateral movement drills, and agility drills. Shuttle runs and sprints used a funnel design, with the volume (total distance) progressing from high (274 meters (m)) to low (27 m) which dictated that the intensity progresses from low to high. Sprint training has been reported to induce neural adaptations, specifically increased nerve conduction velocity and motor-neuron excitability.[12] Agility and lateral movement (line, cone, and ladder) drills progressed from simple patterns with shorter duration, distance, or volume to more complex patterns with longer duration, distance, or volume. Agility drills included line, cone, ladder drills, and advance shuttle and combined skills activities.

The Day-2 workout session was designed to improve muscular strength and muscular endurance, with the focus of increasing total body muscular strength. Strength training consisted primarily of resistance exercises that required no to a minimal amount of equipment and therefore

TABLE 1   **ETAP Design/Overview**

DAY 1: Anaerobic Conditioning	DAY 2: Resistance I
Shuttle runs, sprints, lateral movement, and agility Shuttle runs and sprints use a funnel design through an eight week cycle. The longest distance (274 m) will be performed early progressing to the shortest (27 m) distance. The volume (total distance) progresses from high to low which dictates that the intensity must progress accordingly, from relatively low to high. Agility and lateral movement drills will progress from simple patterns and shorter duration or distance to more complex patterns and longer duration or distance.	Strength training consist of performing exercises using no equipment to a minimal amount of equipment, that can be executed anywhere. The goal is to increase total body muscular strength. The workouts are balanced for total body development; front/back, left/right, and top/bottom.
DAY3: Aerobic Intervals/Balance drills	**DAY 4:** Resistance II
Aerobic intervals include running distances ranging from 800 – 1200 meters, individual dependent, for time followed by active or passive recovery. Interval run time goals is from 3:30 – 5:00 minutes. The number of aerobic intervals progresses from 3 – 5 depending on group and program length. Interval running recovery duration will progress from a longer to shorter time period, initially a 1:1 work to rest ratio. Static and dynamic balance drills are performed with eyes open and eyes closed. Progression is dependent on group ability.	Builds on Day 2, Resistance I workout. Strength training consist of performing exercises using no equipment to a minimal amount of equipment, that can be executed anywhere. Includes basic resistance training exercises along with upper and lower body plyometric exercises. The goal is to improve muscular strength and power.
DAY 5: Aerobic Conditioning	
Distance runs and foot marches are performed. Runs and foot marches can be executed in formation or in ability groups. The goal is to increase VO_{2max} and foot march efficiency and progresses from shorter to longer distances.	

Initially subjects were assigned to one of three interval distances based on APFT two-mile run times ($\leq$ 15:00, 1200m; 15:01 - 17:59, 1000 m; $\geq$ 18:00, 800m). When a subject consistently finished the interval run in less than four minutes or greater than five minutes, then he/she was moved into a longer or shorter distance group, respectively. Prior to the workout, each Soldier was given an individualized goal time to complete the interval runs, based on the average time for his/her interval runs from the previous week. The work to rest ratio was designed to be close to 1:1, but varied by individual due to group size and individual finishing times. Early in the eight-week cycle, the rest time was slightly higher than the work time. As the cycle progressed, the rest time decreased slightly (with a minimum of 4:30 minutes). Also, the cycle began with two to three intervals with five minutes of rest/recovery and gradually progressed to four to five intervals with 4.5 minutes of rest/recovery. Static and dynamic balance drills also were performed at the completion of this workout. Several variation of one leg balance drills with eyes open and eyes closed were also performed.

The Day-4 workout session was designed to improve muscular strength and explosive power. This session built on the main workout session from Day-2. As with Day-2, the volume was manipulated throughout the cycle by altering the time that the exercises were performed. During the first four weeks of the cycle, circuit training which incorporated full body exercises along with upper and lower body plyometric exercises was performed. During weeks five and seven, the IBA was worn during the circuit, with no IBA during weeks six and eight to allow for rest/recovery. Proper landing technique was taught and landing drills executed to decrease ground reaction forces, which were identified in the companion paper as suboptimal. Intensity and volume of plyometric exercises were carefully monitored and introduced according to safety recommendations.[17, 18] Lower body plyometric exercises have been shown to reduce GRF due to a strength increase in the hamstring muscles accom-

could be executed anywhere. Equipment employed included the following: Interceptor Body Armor (IBA), body weight, sandbags, partner resistance, resistance tubing, and dumbbells. Exercise intensity, volume and rest were prescribed according to a recommendation by the American College of Sports Medicine[13] and the volume was manipulated throughout the cycle by altering the duration the exercises were performed. The workout session incorporated full body strength training to ensure a well balanced program and exercises were selected specifically to address muscle weaknesses and/or imbalances as identified during *Predictors of Injury and Optimal Performance*. Targeted muscles included hip adductor/abductor, hamstrings, the rotator cuff and trunk rotators.

The Day-3 workout session was designed to improve aerobic capacity through interval runs.[14, 15] The distance for the interval run ranged from 800-1200m, with the interval run lasting between four to five minutes and performed at or near VO_{2max}. Running faster than VO_{2max} pace does not necessarily produce a greater aerobic benefit; therefore, the interval distance was carefully monitored and adjusted individually.[16]

panied by an improvement in the flexion/extension ratio.[19-22] Teaching and utilizing proper landing techniques also reduces the impact forces, therefore decreasing the risk of injury.[23] Training volume for lower body plyometric exercise was limited to 40-60 landings (4-6 exercises) per session and the jump intensity was limited to vertical jumps, tuck jumps, lateral and front-to-back line and cone hops/jumps, jumping rope, five dot drill and small box drills and landings. Upper body plyometric activities included APFT speed pushups, clapping pushups, and a variety of medicine ball exercises.

The Day-5 workout session was designed to improve aerobic endurance. Distance runs and foot marches were performed on alternate weeks. The goal was to increase aerobic capacity (VO_{2max}) and foot march efficiency and therefore progressed from shorter to longer distances. For the foot march, the minimum pace was set at three miles per hour (20 min/mile) as per Fort Campbell standards. The initial distance was three miles and was increased by a half mile each march. Additionally, the load carried was gradually increased as follows: no load, IBA/Advance Combat Helmet (ACH), IBA/ACH with a 6.8 kg rucksack, and IBA/ACH with a 11.4 kg rucksack. Distance runs began with two to three miles at a steady pace and gradually progressed up to six miles.

Experimental Design

A pretest/post test randomized controlled design was used for this study. All subjects reported to the Human Performance Research Center for pre- and post-intervention testing. The experimental group participated in ETAP under the direction of an ETAP Strength and Conditioning Specialist while the control group performed current physical training at Fort Campbell as governed by FM 21-20 for the eight-week study period under the direction of the groups Physical Training Leader. Subjects reported each morning, Monday through Friday, at the regularly scheduled physical training time, for eight weeks. The ETAP Strength and Conditioning Specialist and Physical Training Leader were solely responsible for instructing physical training and were not involved with the data collection procedures.

Laboratory Testing

The laboratory testing procedures used to evaluate the effectiveness of ETAP to modify biomechanical, musculoskeletal, and physiological characteristics were identical to those described in *Predictors of Injury and Optimal Performance* of Warrior Model for Injury Prevention and Human Performance: Eagle Tactical Athlete Program (ETAP) – Part I. For the sake of brevity and repetitiveness any protocol deviations from the companion paper and related variables are described below.

A low back and hamstring flexibility protocol was assessed with the Novel Products Acuflex® I Sit and Reach Box (Rockton, IL). With shoes removed, the subject sat on the floor with the knees straight and feet flat against the box. The subject placed one hand on top of the other with the fingers aligned and then reached out as far as possible without jerking or bouncing while ensuring the hands stayed in proper position and paused momentarily for measurement. The average of three trials was recorded.

Field Testing

Maximum vertical jump height was determined using the Vertec (Questtek Corp, Northridge, CA). Standing reach was obtained and recorded by having the subject stand directly under the Vertec and extend the dominant arm and hand to gently touch the highest vane possible. Each subject performed a standing countermovement jump for maximum height, reaching the highest vane on the Vertec. Vertical jump was obtained by determining the difference of the maximum jump height and standing reach. A 30-60 second (s) rest was provided between trials. The average of three trials was recorded.

The standing broad jump was measured as the subject performed a countermovement and a two legged forward jump for maximal distance (standing broad jump). Subject's arms were free to move throughout performance of the standing broad jump. Subjects were allotted approximately 30-60 s rest between trials. Distance was measured between the starting position and the most posterior heel-ground contact without the subject falling. The average of three trials was recorded.

The agility task was performed as the subject started in a two point stance straddling the middle cone of three cones, each separated by 4.6m. The subject sprinted (either direction) to the adjacent cone, touched the line with the outside hand and changed direction (ensuring not to pivot all the way around), sprinting past the middle cone to the far cone. The subject touched the line with the outside hand, changed direction, and sprinted past the middle cone, which was the finish line. The time to complete the drill was averaged across three trials. Subjects were allotted approximately 30-60 s rest between trials.

The shuttle run was performed in a straight line between two

Table 2 Pre- and Post-Static/Dynamic Balance (Mean ± SD)								
101st Airborne Division (Air Assault)								
	Exp - Pre		Exp - Post		Control - Pre		Control - Post	
A/P EO (NM)	2.5 ±	0.6	2.3 ±	0.5	2.5 ±	0.6	2.5 ±	0.8
M/L EO (NM)	3.0 ±	1.0	2.9 ±	0.8	3.2 ±	0.8	3.4 ±	1.1
V EO (NM)†	4.3 ±	1.7	4.1 ±	1.6	4.5 ±	1.7	4.6 ±	2.2
A/P EC (NM)†	6.7 ±	3.5	5.1 ±	1.5	7.0 ±	3.6	6.2 ±	2.1
M/L EC (NM)†	9.5 ±	3.8	7.8 ±	2.1	10.1 ±	3.7	9.5 ±	3.1
VEC (NM)	14.2 ±	10.1	10.3 ±	4.0	15.2 ±	11.2	12.7 ±	5.6
MLSI (NM)	0.03 ±	0.01	0.03 ±	0.01	0.03 ±	0.01	0.03 ±	0.01
APSI (NM)	0.15 ±	0.01	0.15 ±	0.01	0.15 ±	0.01	0.15 ±	0.01
VSI (NM)†	0.38 ±	0.04	0.36 ±	0.04	0.38 ±	0.05	0.37 ±	0.05
DPSI (NM)†	0.41 ±	0.04	0.39 ±	0.04	0.41 ±	0.04	0.40 ±	0.05

*Significant pre/post intervention between group differences (p < 0.05)
†Significant pre/post intervention experimental group differences (p < 0.05)
#Significant pre/post intervention control group differences (p < 0.05)

Table 3
Pre- and Post-Flexibility (Mean ± SD)

	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Active Knee Extension (deg)*#	21.6 ± 8.1	20.7 ± 8.8	24.4 ± 8.6	28.5 ± 9.2
Ankle Plantarflexion (deg)	54.4 ± 7.5	51.5 ± 8.3	55.6 ± 5.7	52.5 ± 5.5
Ankle Dorsiflexion (deg)*†	9.2 ± 6.0	10.7 ± 4.7	10.6 ± 5.0	9.5 ± 4.7
Low Back/Hamstring (cm)*†	17.2 ± 2.7	18.6 ± 2.4	15.6 ± 4.1	15.6 ± 4.0
Torso Rotation (deg)*†#	68.7 ± 11.7	77.6 ± 12.4	72.3 ± 7.7	68.2 ± 7.9

*Significant pre/post intervention between group differences (p < 0.05)
†Significant pre/post intervention experimental group differences (p < 0.05)
#Significant pre/post intervention control group differences (p < 0.05)

Table 4
Pre- and Post-Strength (Mean ± SD)

	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Knee Flex (%BW)†	119.1 ± 29.3	128.0 ± 29.5	118.1 ± 25.4	122.6 ± 19.5
Knee Ext (%BW)*†#	236.0 ± 48.9	244.1 ± 42.3	243.3 ± 50.6	223.4 ± 31.8
Knee Flex/Ext Ratio	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.1
Shoulder Int Rot (%BW)	54.0 ± 15.1	53.0 ± 16.0	53.4 ± 12.7	52.8 ± 9.9
Shoulder Ext Rot (%BW)	42.4 ± 9.1	38.1 ± 7.3	42.3 ± 7.7	39.8 ± 6.1
Shoulder ER/IR Rot Ratio	1.3 ± 0.3	1.4 ± 0.4	1.3 ± 0.2	1.3 ± 0.2
Torso Rotation (%BW)*†	128.5 ± 33.5	137.6 ± 27.4	137.7 ± 26.8	136.9 ± 30.5

*Significant pre/post intervention between group differences (p < 0.05)
†Significant pre/post intervention experimental group differences (p < 0.05)
#Significant pre/post intervention control group differences (p < 0.05)

Table 5
Pre- and Post-Physiology (Mean ± SD)

	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Body Fat (%BF)	19.0 ± 7.5	18.9 ± 7.9	18.7 ± 7.3	19.3 ± 7.1
Anaerobic Power (W/kg)*†#	11.9 ± 2.3	14.0 ± 2.4	11.7 ± 2.2	12.7 ± 2.2
Anaerobic Capacity (W/kg)†#	7.5 ± 1.2	8.1 ± 1.0	7.2 ± 1.3	7.6 ± 1.0

*Significant pre/post intervention between group differences (p < 0.05)
†Significant pre/post intervention experimental group differences (p < 0.05)
#Significant pre/post intervention control group differences (p < 0.05)

Table 6
Pre- and Post-Field Tests (Mean ± SD)

	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Vertical Jump (cm)*†#	54.4 ± 11.9	56.6 ± 11.7	55.6 ± 10.2	56.6 ± 10.4
Horizontal Jump (cm)†#	194.1 ± 33.3	201.9 ± 32.8	192.0 ± 27.4	197.1 ± 29.7
Pro Agility (s)*†	5.4 ± 0.5	5.3 ± 0.4	5.4 ± 0.5	5.4 ± 0.4
Shuttle Run (s)*†	69.2 ± 6.2	66.8 ± 6.3	71.0 ± 8.0	71.3 ± 8.5

*Significant pre/post intervention between group differences (p < 0.05)
†Significant pre/post intervention experimental group differences (p < 0.05)
#Significant pre/post intervention control group differences (p < 0.05)

Table 7
Pre- and Post-APFT (Mean ± SD)

	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Pushup (reps)	51.7 ± 13.0	53.3 ± 9.0	53.6 ± 13.9	54.4 ± 12.3
Situp (reps)*†#	58.9 ± 13.3	68.0 ± 10.0	58.6 ± 8.6	62.5 ± 9.8
2 Mile (min)*†#	16.6 ± 2.4	15.4 ± 2.0	16.6 ± 2.6	16.0 ± 2.0

*Significant pre/post intervention between group differences (p < 0.05)
†Significant pre/post intervention experimental group differences (p < 0.05)
#Significant pre/post intervention control group differences (p < 0.05)

Table 8
Pre- and Post-Biomechanics (Mean ± SD)

	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
HipFlexIC (°)	39.7 ± 11.5	41.6 ± 11.7	40.3 ± 10.0	42.2 ± 9.9
HipAbdIC (°)	-5.1 ± 3.5	-4.3 ± 3.8	-4.4 ± 3.8	-4.6 ± 3.4
KneeFlexIC (°)	24.3 ± 8.2	25.1 ± 7.5	23.4 ± 8.3	24.7 ± 7.7
KneeVVIC (°)	3.2 ± 5.0	2.9 ± 4.8	4.1 ± 6.6	1.5 ± 5.7
KneeFlexMax (°)	89.0 ± 12.0	87.9 ± 10.5	85.4 ± 14.3	86.4 ± 9.7
PeakvGRF (%BW)	209.9 ± 49.0	197.0 ± 48.1	254.7 ± 71.2	232.3 ± 60.6
AnkleFlexIC (°)	-7.1 ± 14.2	-5.4 ± 14.9	-5.9 ± 16.1	-7.2 ± 15.6
AnkleFlexMax (°)	26.2 ± 5.7	25.3 ± 5.0	25.9 ± 5.1	25.2 ± 4.1

*Significant pre/post intervention between group differences (p < 0.05)
†Significant pre/post intervention experimental group differences (p < 0.05)
#Significant pre/post intervention control group differences (p < 0.05)

ETAP ICS CURRICULUM

Day 1	Day 2
0930 - 0945 Introduction to ETAP ICS	0930 - 0945 Performance testing information: Classroom brief
0945 - 1000 Paperwork: Informed Consent	0945 - 0950 Transition to gym for Day 2 workout
1000 - 1130 ETAP Day 1 Workout	0950 - 1120 ETAP Day 2 Workout
· Anaerobic intervals	· Full body resistance training day
· Energy pathways	1120 - 1130 Question and Answer period
· Cone drills	1130 - 1300 Lunch break
1130 - 1300 Lunch break	1330 - 1430 Nutrition for athletes: Classroom presentation
1300 - 1330 Introduction to ETAP	· Basic nutrition concepts
Basic exercise physiology presentation	· Sports nutrition concepts
1330 - 1345 Dynamic warm up: Classroom presentation	· Weight control information
1355 - 1405 Static stretching: Classroom presentation	· Supplements: Use of and cautions
1405 - 1415 Break	1430 - 1440 Break
1415 - 1425 Dynamic warm up: Practice and corrections in gym	1440 - 1520 Resistance I/Strength Training: Classroom presentation
1425 - 1450 Anaerobic conditioning: Classroom presentation	· Principles/guidelines and proper techniques
1450 - 1515 Agility, balance, & coordination:	· Muscle contraction
Walkthrough/Interactive presenation in gym	· Partner resisted exercise
1515 - 1530 Agility ladder drills: Practice and setup	· Alternative forms of resistance
	· Alternative forms of workouts
	· Workout considerations
	1520 - 1525 Aerobics intervals (Day 3 Preview): Classroom
	1525 - 1530 Question and Answer period

Day 3	Day 4
0930 - 1100 ETAP Day 3 Workout	0930 - 1110 ETAP Day 4 Workout
· Aerobic intervals	· IBA Workout
· Static balance drills	· Medicine ball exercises
1100 - 1120 Balance drills discussion: Static and dynamic	1110 - 1120 Alternative forms of resistance: Show and tell
1120 - 1130 Question and Answer period	1120 - 1130 Question and Answer period
1130 - 1300 Lunch break	1130 - 1300 Lunch break
1300 - 1400 Aerobic intervals/interval running: Classroom presentation	1300 - 1320 Landing and IBA Workout: Classroom presentation
	1320 - 1325 Discussing & interpreting heartrate graphs
· Interval running concepts	1325 - 1400 Resistance II: Classroom Presentation
· Energy pathways	1400 - 1410 Break
· VO2max and LT concepts/theories	1410 - 1420 Exercise demonstrations and suggestions from Physical Training observations: in gym
· LT improvement concepts	
· Measuring intensity: RPE & heartrate	1420 - 1430 Push press: Discussion and demonstration
· Using heartrate monitors and software	Medicine ball and push press: Practice in gym
· Field measures of aerobic	1430 - 1500 Functional and agility training: Discussion, demonstration, and practice various forms of:
1400 - 1410 Discussin & interpreting heartrate graphs	
1410 - 1420 Break	· Hops: line and cone
1420 - 1510 Partner resisted exercise: Practice in gym	· Vertical jumps
1510 - 1520 Proper squat technique: Discussion and practice	· Jump rope intensities
1520 - 1530 Question and Answer period	· Unstable surface training
	1500 - 1515 Putting it all together: Classroom presentation
	1515 - 1525 Workout cards and DVD: Explanation
	1525 - 1530 Course evaluation and distribution of Certificates of Completion

cones, separated by 22.9m and timed for a total completion of 274.3m (six laps). Subjects were instructed to touch the end lines with their hands prior to change in direction. One trial was completed and recorded.

The APFT was conducted by a non-commissioned officer in charge responsible for administering and scoring the individual components of the APFT. Subjects were allotted two minutes to perform maximum repetitions of sit-ups, two minutes to perform maximum repetitions of push-ups, and timed two mile run according to APFT standards as outlined in FM 21-20. A 10-minute rest period was allowed between each testing component.

Statistical Analysis

Data were examined to assess the assumptions of normality and of equality of variance. These assumptions were not met in the case of some variables. Descriptive statistics (measures of central tendency and measures of dis-

persion) were estimated for all variables. The absolute differences from pre- and post-testing for the experimental and control group were calculated for all variables. Both parametric tests for normally distributed data and non-parametric tests were used to compare absolute differences from baseline between the experimental and the control group. The results of the non-parametric test (Wilcoxon rank-sum test) agreed with the results of the corresponding parametric test (independent samples t-test) with respect to direction of change and significance of the results in the majority of the variables and reported as parametric analysis. Statistical significance was set at $p < 0.05$ for all variables.

Results

The 8-week trial was comprised of 35 training sessions and accounted for five days of no scheduled activities according to the Fort Campbell operating schedule. The average attendance for the experimental group was 89% (31

sessions) with a range of 54-100%. A minimum attendance of 80% of the training sessions was achieved by 80% of the subjects in the experimental group. The average attendance for the control group was 94% (33 sessions) with a range of 71-100%. A minimum attendance of 80% of the training session was achieved by 96% of the subjects in the control group.

Flexibility/range of motion, strength, and balance data are presented in Tables 2- 4. Compared to the control group, the experimental group demonstrated improved active knee extension (p < 0.001), ankle dorsiflexion (p = 0.018), lumbar/hamstring flexibility (p < 0.001), and torso rotation flexibility (p < 0.001). No significant group differences were demonstrated in ankle plantar flexion (p > 0.05). Compared to the control group, the experimental group demonstrated significant improvements in knee extension strength (p < 0.001) and torso rotation strength (p = 0.036). No significant group differences were demonstrated in knee flexion or shoulder strength (p > 0.05). No significant group differences were demonstrated in eyes open or eyes closed balance (p > 0.05).

Physiological, field assessment, and APFT data are presented in Tables 5- 7. No significant group differences were demonstrated for percent body fat (p > 0.05). Compared to the control group, the experimental group demonstrated significant improvements in anaerobic power (p = 0.019). Compared to the control group, the experimental group demonstrated significant improvements in the sit-up (p = 0.022) and two mile timed run (p = 0.039) portions of the APFT, vertical jump (p = 0.042), agility (p = 0.019), and 300 yard shuttle run (p = 0.005).

Biomechanical data are presented in Table 8. No significant differences were demonstrated for the biomechanical variables (p > 0.05).

DISCUSSION

The purpose of this paper was to detail the last three steps of the injury prevention and performance optimization model: *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program*. The Eagle Tactical Athlete Program (ETAP) is a comprehensive physical training program for performance optimization and injury mitigation and was based on the tasks and demands of the 101st Airborne Division (Air Assault) Soldiers. It was demonstrated to induce favorable adaptations to a significant number of modifiable characteristics following eight weeks of training as indicated by improvements in strength, flexibility, balance, power, field tests, and APFT. Although several variables did not demonstrate improvements, the authors acknowledge limited exposure with an 8-week program may have contributed to such results. The program duration will be accounted for when periodized to meet the pre-deployment training cycle of 10-12 months. The effectiveness of ETAP to reduce the risk of unintentional musculoskeletal injuries and optimize physical readiness and performance in Soldiers of the 101st Airborne will be assessed over the next year.

Flexibility/range of motion of the hamstring, calf, and torso improved in the experimental group relative to the control group. The results indicate that dynamic stretching with warm-up and static stretching with cool-down as incorporated with ETAP are effective ways to improve flexibility compared to static stretching with warm-up typically seen in the traditional PT. Improvements in flexibility and range of motion may be important in decreasing the risk of musculoskeletal injuries. Hartig and Henderson[24] reported that hamstring flexibility improved in military infantry basic trainees who participated in a stretching intervention and that these trainees also sustained significantly fewer lower extremity overuse than the controls during a 13-week infantry basic training course. It has also been reported that individuals with less hamstring flexibility, measured using a variety of techniques, are significantly more likely to develop hamstring and quadriceps muscle injuries, low back pain, and patellar tendinitis.[25-27] Decreased flexibility of the gastroc-soleus complex (either alone or in conjunction with other variables) has also been identified in increasing the risk of patellofemoral pain syndrome, achilles tendinitis, ankle sprains, and medial tibial stress syndrome.[28-31]

Knee extension, knee flexion, and torso rotation strength improved in the experimental group relative to the control group. Lower levels of strength may be associated with an increased risk of injury or may be a residual effect from a previous injury. In a prospective study of Australian footballers, Orchard et al. reported that hamstring injury was significantly associated with hamstring weakness as measured by peak torque at 60°/sec.[32] Decreased hamstring strength has also been identified in female athletes who subsequently sustained an injury to the anterior cruciate ligament as compared to male matched controls.[33] Individuals with a history of low back pain demonstrate significantly lower trunk strength than controls.[34] As a general guideline for resistance training, the intensity of 70-80% of one repetition maximum for eight to twelve repetitions and three sets for two to three times a week is recommended for novice athletes.[35] The volume and intensity utilized in ETAP were similar to these recommendations. No significant improvements were seen in shoulder strength, which may be the result of an increased focus of lower body strength and endurance.

Single-leg balance with eyes closed was improved in the experimental group; however, no significant differences with eyes open or group differences were demonstrated. Several studies analyzed biomechanical and neuromuscular characteristics after neuromuscular training (typically a combination of plyometric, resistance, balance, perturbation, and agility training) and reported increases in balance performance.[21, 36, 37] Myer et al.,[21] included several dynamic balance exercises on an unstable disc three times a week for seven weeks. The current study incorporated balance exercises once per week and the balance exercises were performed on a stable surface, which was sufficient to improve single-leg balance with the eyes closed. It is possible the lack of significant group differences in the current study may be multifactorial such that both the low frequency and intensity/difficulty of balance exercises were not sufficient to induce large enough changes. In addition, balance, particularly

with the eyes open, may be positively impacted by other training modalities (e.g., squats, lunges, ruck marches on an uneven surface) to which both groups may have been exposed.

Neither group demonstrated a significant change in body weight nor percent body fat. Although exercise training increases energy expenditure which may contribute to a negative energy balance and thus body weight loss, numerous studies have found that exercise alone results in little if any weight loss[38-40] This is explained in part by the fact that moderate exercise does not create a large enough energy gap to promote body weight loss.[38] ETAP training was intended to induce adaptations to promote aerobic fitness, anaerobic power and capacity, muscular strength, flexibility, and balance, not necessarily to promote body weight loss. Also, none of the Soldiers in the current study received any instructions on modifying their diets. There is little evidence to suggest exercise alone will provide the amount of weight loss similar to that generally achieved by diet restriction.[38, 39] Research has shown that higher levels of exercise and or the addition of energy restriction may be necessary to promote significant body weight and fat loss[39, 41-43]

Relative to the control group, the experimental group demonstrated significant improvements in anaerobic power. During the Wingate test, higher anaerobic power is a function of pedaling speed and torque. It is possible that this improvement in anaerobic power resulted from training effects induced by the sprinting and agility exercises along with resistance exercises performed during ETAP. The experimental group also demonstrated a significant improvement in anaerobic capacity. These improvements may be the result of interval training and the varied intensity of exercise that was provided during ETAP. Significant improvements in agility and the shuttle run were seen in the experimental group as compared to the control group. These adaptations may be the result of the targeted training provided by ETAP. Many athletic movements and tactical maneuvers rely on anaerobic capacity, power, and a combination of agility-type activities.

In terms of the APFT, the cardinal assessment of fitness in the U.S. Army, the experimental group demonstrated significant improvements in the sit-ups and two mile run relative to the control group. The key finding is that ETAP was able to improve two mile run performance without the high running mileage typical seen with Army PT. The results of the current study, when combined with previous epidemiological studies, indicate that it may be possible to reduce the incidence of injury during military training by reducing running mileage without compromising fitness as assessed by the APFT.[44-46]

No significant improvements in any of the biomechanical characteristics were seen in either group. Previous research that investigated the effect of plyometric programs coupled with resistance programs on lower extremity kinematics has produced conflicting results.[21, 43, 48] Myer et al.,[21] reported an increase in hip abduction angle and no changes in knee valgus/varus angle after seven weeks of a plyometric training program and a balance training program. Lephart et al.,[47] reported an increase in knee flexion and hip flexion following an eight-week program that incorporated resistance, balance, and plyometric training. However, no changes in knee valgus/varus and hip abduction angle were observed. Similarly, Chappell et al.,[48] reported an increase in knee flexion angle and no changes in knee valgus/varus and hip abduction angle after six weeks of neuromuscular training. The validation trial of ETAP was based on an 8-week trial and may not have been a sufficient duration to induce biomechanical adaptations during landing activities as ETAP was designed to improve multiple areas throughout the 8-week trial with the understanding of eventual expansion to a pre-deployment cycle.

There are several limitations to the current study. Although the U.S. Army provides field manuals to guide physical training, physical training is administered at the discretion of the unit leader and can vary extensively within a Division. It was requested of the Physical Training Leader that he instruct physical training for the control group as he would if not participating in the trial. Within the Division this could suggest an overlap in training or similar training being performed relative to the experimental group. In addition, many military personnel train on an individual basis to supplement unit PT but were instructed to restrict outside exercise/training beyond morning physical training while enrolled in the 8-week trial. This was not monitored in the current study, however if performed, this training may have enhanced the results of the control group to improve certain characteristics. Soldiers performing ETAP demonstrated significant improvements in several variables that are vital to optimizing physical readiness and performance and potentially reducing the risk of unintentional musculoskeletal injuries. Implementation of ETAP into the Division should have long-term implications to improve physical readiness of the Soldier when periodized across a 10-12 month pre-deployment cycle when sufficient exposure and duration is achieved for all components of physical training to allow for complete adaptation of the suboptimal characteristics.

The Department of the Army has recognized the need for updated physical training guidelines to better address more aspects of physical fitness in order to improve performance and physical readiness while reducing the risk of injury. The Army replaced FM 21-20, which was the guideline that governed physical training being performed at Fort Campbell at the time of this study, with TC 3-22.20, *Army Physical Readiness Training*.[10] Epidemiological studies have demonstrated the effectiveness of PRT to reduce injuries while maintaining or improving APFT during Basic Combat Training (BCT) and Advanced Individual Training (AIT).[44-46]

Future studies and programs should incorporate more upper body training. No changes in upper body strength were demonstrated in either group. However, previous studies have reported a high incidence of shoulder instability, dislocation, and rotator cuff tears in the military population[49-51] and that reduced shoulder internal and external rotation peak torque is typically seen with shoulder impingement syndrome and instability.[52-54] Future studies should also monitor and attempt to further control for physical training performed out-

side of daily Army PT. Finally, it is important to incorporate meal planning and nutritional educational sessions in any injury prevention and performance optimization program if body composition changes are desired.

The final two steps of the public health approach to injury prevention and control: *Program Integration and Implementation* and *Monitor and Determine the Effectiveness of the Program* are currently ongoing and will be completed over the next year. *Program Integration and Implementation* includes the ETAP Instructor Certification School (ICS). ICS is a four-day program designed to teach physical training leaders (NCOs) how to implement and effectively instruct ETAP at the unit level and is based on the Army concept of "train-the-trainer". The final step: *Monitor and Determine the Effectiveness of the Program* will test the effectiveness of ETAP to mitigate musculoskeletal injuries and optimize physical readiness and performance. A parallel approach has been adopted to include injury surveillance both during garrison and deployment and prospective interval testing of laboratory, performance, and APFT variables.

To date, 952 Soldiers have participated in ICS. Soldiers enrolling in ICS are non-commissioned officers (NCO) who regularly instruct morning physical training. Part of each graduate's responsibility is to teach ETAP to other Soldiers who are unable to attend ICS and instruct at the unit level. Two NCOs (a senior and junior NCO) per platoon participated. To recruit an equal number of Soldiers from each Brigade and accelerate Division-wide implementation, six to eight ICS sessions (weeks) were scheduled for each Brigade, with the unit assignment based on the Brigade's and Division's pre-deployment training cycle. The goals of ICS include: 1) experience and understand a comprehensive physical fitness program, 2) understand the components and underlying principles of ETAP to effectively adapt it to individual or unit situations, and 3) develop a working understanding of how to implement ETAP with little to no equipment to ensure that the program is deployable. Daily activities over the four-day course allow for participants to achieve these goals through a multifaceted learning approach. The Soldiers were familiarized with the exercises and the program through participation in ETAP training sessions; interactive sessions including traditional lectures and presentations as well as open discussion to ensure proper understanding of the theory behind the program. Proper technique, progressions, and corrections for the exercises, and alternative exercises and/or training that can be employed while still accomplishing the same goals are covered during "hands on" practice sessions to implement and instruct ETAP. A course outline for ICS is summarized in Table 9. Day 1 covered basic exercise physiology, warm-up/cool-down, stretching, anaerobic conditioning, and agility exercises. Day 2 covered nutrition and resistance exercises. Day 3 covered aerobic interval workouts, balance exercises, partner resistance exercises, and proper lifting techniques. Day 4 covered plyometric exercises, IBA workouts, medicine ball exercises, landing techniques, and PT program design. At the completion of ICS, students received the eight week ETAP workout cards along with the corresponding DVD. The DVD contains all of the lecture slides, a written description and videos of all exercises performed, exercise progression guidelines, perceived exertion and heart rate guidelines as well as information to develop alternative ETAP exercises given the deployment environment. The validated 8-week ETAP program has been extended according to each Brigade's pre-deployment training schedule with repeated cycles of increasing intensity. The training cycles contain the same principles by which the 8-week model was developed, but modified the progression of each training modality. The weekly training format is identical with individual days dedicated to different components of fitness, yet allowing for combat focus training. Based on ICS enrollment, 40 Soldiers per platoon, and an instructor to Soldier ratio of 2:40 or 1:20 per platoon, approximately 19,500 Soldiers have been exposed to ETAP at the unit level. This ratio allows for adequate supervision of Soldiers performing ETAP, ensuring that proper technique and progressions are maintained. In addition, quality control audits are conducted by personnel from the University of Pittsburgh, ensuring proper delivery of ETAP by the NCOs to their respective units and allowing for implementation-related questions to be answered and assessment of exercise performance/technique of the Soldiers at the unit level.

To date, 1478 out of a projected 2000 Soldiers have been enrolled in step six, *Monitor and Determine the Effectiveness of the Program*. Soldiers from a representative Brigade performing ETAP are participating in this aim as the experimental group while Soldiers from a separate Brigade which performs comparable tactical operations and is deployed to a similar location/environment are serving as the control group. To participate, Soldiers must spend a minimum of six months at garrison and 12 months deployed during participation. History of injuries prior to the study start date will be used to compare the frequency of injuries at baseline between the ETAP and regular Army PT groups. The proportion of subjects with unintentional injury will be compared between the ETAP group and the regular Army PT group at the end of 18 months of follow up, by Chi-square tests. A Kaplan-Meier survival analysis will be used to compare time to injury between the two groups. A Cox regression will be used to adjust for variables such as gender, age, number of months of exposure to the ETAP, years of service, and deployment status.

Summary

The purpose of this paper was to describe the last three steps of the injury prevention and control model: *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program* as studied with the 101st Airborne Division (Air Assault). ETAP is a research-based, comprehensive program developed specifically for the 101st Airborne Division (Air Assault) based on inherent injury epidemiology, task and demand analyses, identification of suboptimal physical and physiological characteristics compared to an athletic benchmark, and previously established injury risk factors.

Although it has been demonstrated that ETAP can positively impact physical readiness in a controlled trial,

prospective injury surveillance must occur to properly and accurately assess the effectiveness of ETAP to reduce the risk of unintentional musculoskeletal injuries in Soldiers performing ETAP. Additionally the prospective analysis of performance is necessary to determine the effectiveness of ETAP to optimize physical readiness when delivered by the Soldiers of the 101st Airborne Division (Air Assault). The effectiveness of ETAP to be implemented into the Division and resultant mitigation of unintentional musculoskeletal injuries and performance optimization is ongoing and will be completed over the next year.

The application of the public health model of injury prevention and control is an effective tool to scientifically develop and implement injury prevention and performance optimization programs for the tactical athlete, regardless of tactical demands. The research model described for the development of ETAP and 101st Airborne Division (Air Assault) is adaptable to culturally-specific units and driven by the task and demand analysis by which the entire injury prevention and performance research model can be implemented within different Special Operations Forces units.

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